PB82-111816

Thermal Conversion of Municipal Wastewater Sludge, Phase II: Study of Heavy Metal Emissions

Interstate Sanitation Commission
New York

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Sep 81

U.S. Department of Commerce
National Technical Information Service
NTIS

PB82-111816

EPA-600/2-81-203
September 1981

THERMAL CONVERSION OF MUNICIPAL WASTEWATER SLUDGE PHASE II: STUDY OF HEAVY METALS EMISSIONS

by

Nichols Engineering and Research Corporation
A Subsidiary of Wheelabrator-Frye, Inc.
Belle Mead, New Jersey 08502

U. S. EPA Grant No. R804463

Project Officer

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Prepared for:

Interstate Sanitation Commission
New York, New York 10019

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
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1. REPORT NO. EPA-600/2-81-203	2. ORD Report	3. RECIP
4. TITLE AND SUBTITLE THERMAL CONVERSION OF MUNICIPAL WASTEWATER SLUDGE, PHASE II: STUDY OF HEAVY METAL EMISSIONS		5. REPORT DATE September 1981
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Nichols Engineering and Research Corporation Homestead and Willow Roads, Belle Mead, N.J. 08502		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Interstate Sanitation Commission 10 Columbus Circle, New York, N.Y. 10019		10. PROGRAM ELEMENT NO. DU B-113, P.E.AZB1B, Task B/08
		11. CONTRACT/GRANT NO. R804463
12. SPONSORING AGENCY NAME AND ADDRESS MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY--Cin., OH OFFICE OF RESEARCH AND DEVELOPMENT U. S. ENVIRONMENTAL PROTECTION AGENCY CINCINNATI, OHIO 45268		13. TYPE OF REPORT AND PERIOD COVERED Final, Aug. 1978-Jan. 1980
		14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

Project Officer: Howard Wall (513) 684-7659

16. ABSTRACT

The object of this work was to compare and analyze heavy metal emissions associated with the thermal conversion (incineration) processes which can be conducted in a multiple-hearth furnace to dry municipal wastewater (sewage) sludge and reduce its volume by forming an ash or char. Sludge for this project was obtained from Jersey City, New Jersey. It contains about 8 percent solids which were increased to between 40 and 50 percent solids by adding polymer as a filter aid and filtering it in a 4 ft x 4 ft pilot filter press having expandable rubber diaphragm plates. A pilot scale multiple-hearth furnace, .91 m (36") 10 x 6 hearth was used for the thermal conversion process. Sludge was subjected to thermal conversion at the conditions: 1. Incineration at 900 °C (1625 °F); 2. Low Temperature Conversion at 700 °C (1290 °F) (starved air combustion or pyrolysis); 3. High Temperature Conversion at 900 °C (1290 °F) (starved air combustion or pyrolysis). Results indicated that the low temperature conversion substantially retained cadmium, lead, and beryllium in the ash or char when compared to incineration. However, the ash retained far more silver during incineration than it did during high or low temperature conversion.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 96
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The purpose of this work has been to develop a workable design for conversion of a plant scale multiple hearth municipal wastewater sludge incineration system to a limited air (oxygen) mode of operation. Ocean disposal of municipal sludge must be discontinued by 1981 and thermal conversion is being tested as a possible environmental acceptable and economical method of municipal wastewater sludge disposal.

Francis T. Mayo
Director
Municipal Environmental
Research Laboratory

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ABSTRACT

The object of this work was to compare and analyze heavy metals emissions in the respirable range associated with the thermal conversion of municipal sewage sludge. Three modes of operation were tested: incineration at 900°C, low-temperature thermal conversion (LTC) at 700°C, and high-temperature thermal conversion at 900°C.

The equipment included a pilot-scale multiple hearth furnace with an afterburner. Particulate samples were collected before abatement with a Source Assessment Sampling System.

A mass balance in and out of the furnace showed that furnace residue contained close to 100% of chromium, copper, iron, manganese, nickel, and zinc present in the sludge filter cakes within an experimental error of 30%. Two to eleven % of these metals present in the filter cakes were confirmed in furnace off-gas particulate matter.

Results indicate that lowering furnace temperature from 900°C to 700°C improves retention of feed metals in the furnace residue from 50% to 90% for beryllium, from 10%-30% to 50% for cadium, and from 30%-50% to 60% for lead. In contrast, silver retention drops from 60% during incineration mode (oxidizing atmosphere) to 20% during the low temperature mode (reducing atmosphere).

This report was submitted in fulfillment of EPA Grant No. R-804463-01-2 by The Interstate Sanitation Commission. This report covers the period from August 28, 1978 to June, 1979 and work was completed as of January 15, 1980.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

AA	-- atomic absorption spectroscopy
AB	-- afterburner
BOD	-- biological oxygen demand
CST	-- capillary sunction time
EPA-5	-- method five stack sampling train
gr/dscf	-- grains per dry standard cubic feet
HTC	-- high-temperature thermal conversion
ICAP	-- inductively coupled argon plasma spectroscopy
INC	-- incineration
ISC	-- Interstate Santitation Commission
kPa	-- kilopascals
LTC	-- low-temperature thermal conversion
MHF	-- multiple hearth furnace
MRC	-- Montanso Research Corporation
PCB	-- polychlorinated biphenol
RAC	-- radiation and convection
SASS	-- source assessment sampling system
TC	-- total carbon
TOC	-- total organic carbon
TSS	-- total suspended solids
TDS	-- tons dry solids
WTP	-- water treatment plant
XRF	-- X-Ray fluorescence
µm	-- micrometers aerodynamic diameter

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SECTION 1

INTRODUCTION

This report is a part of a study funded by the United States Environmental Protection Agency (EPA) for the Interstate Sanitation Commission (ISC) concerning the disposal of sewage sludge in the New York-New Jersey Metropolitan area. Specifically, this report provides data on heavy metals emissions resulting from incineration and thermal conversion* of sewage sludge, supplementing data that were presented in Phase I report of campaigns I through III. (1).

Campaign IV, reported herein, was conducted between August 21 and September 4, 1978 at a pilot-scale test facility. Sewage sludge obtained from the Jersey City Wastewater Treatment Plant (WTP) was dewatered and the filter cake was subjected to three modes of operation in a pilot-scale multiple hearth furance. The modes of operation were incineration (INC), low-temperature thermal conversion (LTC), and high-temperature thermal conversion (HTC).

Information regarding air pollution, heavy metals distribution, solid product characteristics and heat recovery potential were determined. The data provide determinants for design parameters required for pollution control.

* Defined here as combustion with a controlled, sub-stoichiometric air supply.

1. Nichols Engineering and Research Corporation, PHASE I Report of Pyrolysis of Sewage Sludges.....

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SECTION 2

OBJECTIVES

The object of this work is to compare and analyse the heavy metals emissions in the respirable range associated with three types of thermal conversion of sewage sludge. The respirable range of particulates is defined as those smaller than 10 μm. A complete metals balance is made for the entire dewatering and thermal destruction process. The periodic table in Figure 1 is keyed to indicate the metals referred to in this study.

In previous work, reported for Campaigns I through III, it was shown that sewage sludge thermal conversion was a viable and economic process in a multiple hearth furnace. Analyses from those tests indicated that some heavy metals entering the furnace in the feed were lost to the gas phase. However, no thorough analysis of the heavy metals content of the particulate was attempted.

In Campaign IV, covered by this report, test runs were made during the latter part of August, 1978. The Nichols'* 36" I.D. multiple hearth furnace (MHF) was run in both incineration and thermal conversion (starved air combustion) modes using sludge filter case as a feed.

A contractor, Monsanto Research Corporation (MRC)* collected particulate samples from the gas at a sampling point between the afterburner and scrubber (See Figure 2, Sample Point 6). MRC determined particle size distribution and metals concentration within each particle size from these samples. MRC also determined SO_2, NO_2, and hydrocarbon concentrations in the afterburner gases (Sample Points 5 and 6).

The Interstate Sanitation Commission (ISC) determined the metals content of the sludge feed (Sample Point 1) sludge cake (Sample Point 2), filter press filtrate (Sample Point 3), sludge ash (Sample Point 4), metals content of EPA-5 filter pads (Sample Point 6), scrubber water (Sample Point 7), and tap water (Sample Point 8). Where applicable ISC also determined chlorodane, dieldrin, PCB, pH, TSS, TC, TOC, and BOD concentrations.

Princeton Testing Laboratory (Route 1, Princeton, N.J.) performed the ultimate analyses for carbon, hydrogen, nitrogen, sulfur, and ash content of sludge cake samples.

* Trade name; use of trade name does not indicate USEPA endorsement.

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IA	IIA	IIIB	IVB	VB	XIB	XIIB	VIIIB			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
H																	He
Li	Be											B	C	N	O	F	Na
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	T	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															

Notes:
1. A total accounting was attempted for circled elements
2. Particulate matter was analyzed for underlined elements
3. Rare-earth metals were beyond the scope of this work

FIGURE 1. ELEMENTS MEASURED IN THIS STUDY

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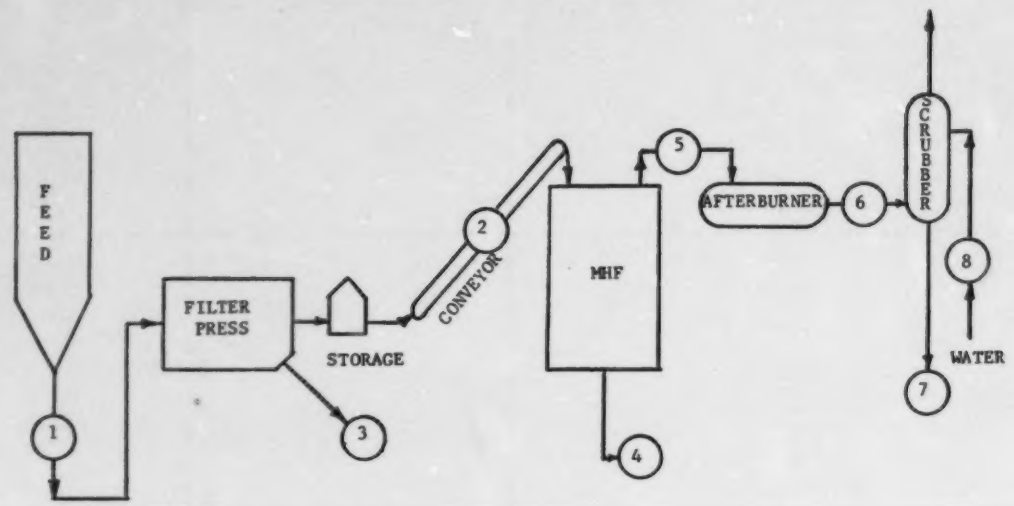
Nichols Engineering and Research Corporation supervised and operated the dewatering and furnace systems. They also determined feed and product heating values, dewatering conditions, and EPA-5 particulate loadings. Nichols performed the data analysis and evaluation for this report.

FIGURE 2

FLOW SCHEMATIC

AND-O DESIGNATED SAMPLE POINTS



1. Sludge sampling
2. Feed sampling
3. Filtrate sampling
4. Hourly furnace residue sampling
5. Analyses for SO_x, NO_x, and hydrocarbons.
6. Particulate sampling via SASS and EPA-5; gas analyses as in 5.
7. Scrubber water sampling
8. Influent water sample (municipal water supply)

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SECTION 3

CONCLUSIONS

Characteristics of Furnace Residue

1. The residue contains 100 ∓ 30% of feed chromium, copper, iron, manganese, nickel, and zinc irrespective of mode of operation or operating temperature in the range studied (up to 900 C).

2. Lowering the multiple hearth furnace operating temperature from 900 C to 700 C improves retention in the furnace residue by a factor of 2 for beryllium, 2 to 4 for cadmium, and 1.2 to 2 for lead.

3. Incoming mercury is almost entirely unaccounted for (less than 1%) by that in the furnace residue.

4. The furnace residue retains 20 to 30% of the feed silver in reducing furnace conditions and 50 to 65% of the feed silver in oxidizing furnace conditions.

5. Amounts of arsenic, selenium, and varadium were present in the furnace residue, but no quantitative conclusions can be drawn from this study.

Characteristics of Unabated Particulates

6. The kg/hr of zinc, cadmium, and lead during the LTC mode of operation were half that of the HTC and INC modes, as a result of lower furnace operating temperatures.

7. Between 2 and 11% of feed silver, chromium, copper, iron, manganese, and nickel were confirmed in the particulates; these metals showed no trend with respect to mode of operation.

8. The distribution of metals among particulate size catches is complex; but by and large metals are much less prominent in the 0.1 to 1.0 μm size fraction.

Other Pollutants Exiting the Afterburner

9. Unabated sulfur dioxide emissions were 23 gm/kg dry feed during INC mode, 11 gm/kg during the LTC mode, and 16 gm/kg during the HTC mode.

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10. The limited feed and product chloride analyses indicate that 2.5 gm/kg dry feed Cl evolved during the INC mode and 1.8 gm/kg Cl evolved during the LTC mode.

11. The large unaccounted fraction of several metals in this study could mean that they are fumed and not collected as particulates; further study is recommended to address this question.

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SECTION 4

RECOMMENDATIONS

It is recommended that any future study of metals emissions from sludge combustion be conducted for a much longer period of time than one week to allow metals to reach an equilibrium concentration in the brickwork, etc. and to establish steadier operating conditions.

It is also recommended that the sampling procedures be refined. First, the stack sampler gas stream should be percolated through reagent to capture possible fumed metals for analysis. Second, the total stack flow should be measured accurately with an orifice plate rather than a pilot tube. Third, stack temperature measurement should be modified as discussed on page 64.

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SECTION 5

PRESENTATION OF EXPERIMENTAL RESULTS AND DATA

Filter Press Work

On August 21-25, 1978, 114,000 liters of sludge were filter-pressed to yield 10,250 kg of filter cake with a 49.0% average moisture content. The sludge used was Jersey City primary settled sludge with 8% solids content.

In all, 31 runs were made including three failures; 366 kg of filter cake were made per run. The runs lasted for 86 minutes, including 39 minutes for filling and 47 minutes for squeezing with the expandable diaphragms. The polymer Percol 757* was used as a flocculant in a concentration of 100-170 mg/kg in the sludge (13. to 4.2 gm polymer/kg dry solids). Three early press run failures were the result of improper conditioning. The press runs were summarized in Table 1.

The apparatus is diagrammed in Figure 3. A pug mill mixed polymer solution with sludge from the tank truck and it also allowed rags and stones to be removed; as they will clog the pumps. The conditioned sludge was then pumped to a holding tank. From the tank it was forced into the press by a Wilden M-15 double diaphram pump at a maximum pressure of 827.4 k Pa (120 psig).

The 1.2 m x 1.2 m (4' x 4') Nichols**filter press had 14 plates, of which alternate plates had expandable diaphrams. After 40 minutes of filling time the sludge flow was stopped and compressed air was used to inflate the diaphragms. When the filtrate flow diminished to 1.5 ℓ/min or so the press was opened and the cakes were dropped. The filter cakes were stored in sealed containers. Samples of filtrate and filter cake solids were taken.

* Trade name; use of trade names does not indicate USEPA endorsement.
**Ibid.

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TABLE 1: FILTER PRESS RUNS

RUN#	CAKE WT. (kg)	% SOLIDS	FILL TIME (MIN.)	SQUEEZE TIME (MIN.)	CST** (SEC.)
1*					
2*					
3	322	46.5	30	60	21.7
4	488	47.8	45	35	
5	490	38.8	47	18	55.5
6*					
7	552	53.4	45	30	15.7
8	479	50.6	40	40	15.7
9	478	42.7	43	41	23.7
10	432	46.2	45	45	
11	407	55.7	45	45	
12	308	49.3	52	80	100
13	449	52.7	45	45	26.0
14	377	47.8	28	55	28.0
15	491		30	45	12.7
16	445	54.2	32	46	15.2
17	150	49.8	34	33	12.3
18	291	57.8	35	Overnight	13.2
19	342	48.3	25	60	18.6
20	469	50.4	35	45	12.6
21	428	50.7	50	45	12.1
22	345		40	45	11.1
23	345	46.8	48	45	7.8
24	270	45.8	42		11.1
25	263	44.5	25		18.4
26	405		45	45	11.4
27	293		50	45	11.4
28	316		35	60	15.9
29			30	73	13.0
30		47.8	32	50	12.5
31		39.2	150		12.3

* Run produced no cake
** Capillary suction test on conditioned sludge.

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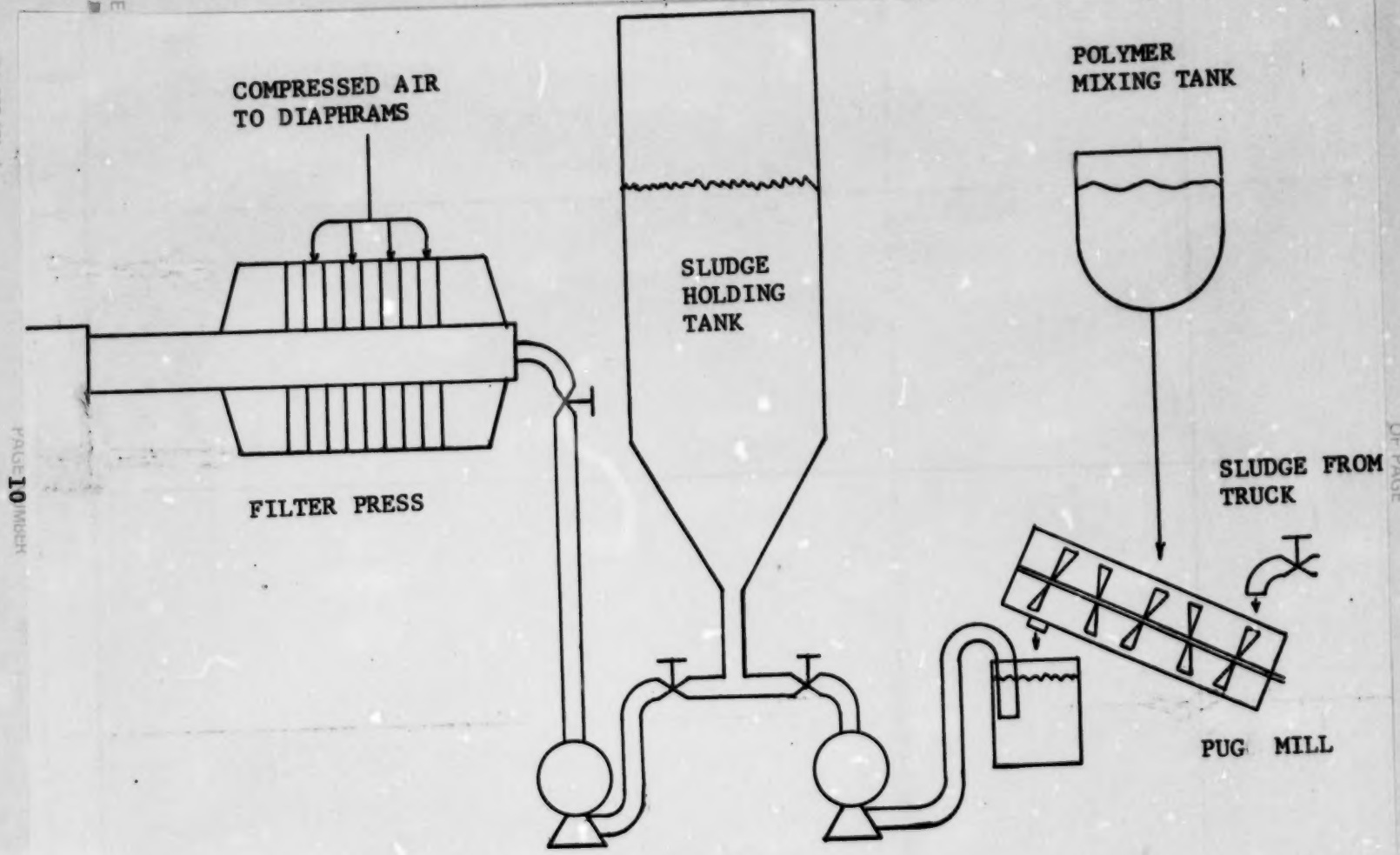

FIGURE 3: FILTER PRESS FLOW DIAGRAM

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Furnace Operation

The furnace used in this test work was Nichols'* Pilot-scale 0.91 m(36") I.D. X 6 multiple hearth furnace (MHF). Filter cake was fed at a rate of 113.3 kg/hr wet (250 wet lb/hr) for a hearth loading of 39 kg/hr.m^2) (8 lb/(hr.ft^2). The rabble tooth pattern (Figure 4) is arranged to move the solids more rapidly through the top hearths and to provide some back mixing in the lower hearths.

The feed was run through a twin roller cake breaker to accomplish two objectives. The cake breaker reduced the lump size to reduce the amount of unburned material in the furnace residue. It also served as a way to mix two filter press batches, one wet and one dry, so that the average moisture content of the two was closer to the overall mean moisture content.

The furnace off-gases were led to a 2.0 m^3 afterburner operated at 870 to 930 C (1600 to 1700 F) with excess air and some fuel added when required. From there they were pulled through a cyclone and scrubber by an I.D. fan.

Furnace Sampling

As exhibited in Figure 2, sample Points 2 and 4 through 8 pertain to the furnace operation. At Point 2, hourly feed samples were composited from 12 minute portions. At Point 4, hourly product samples were taken. Point 5, between the furnace and afterburner, was tested by MRC for NO_x, SO_x and hydrocarbons and also particulates.

The first of the two particulate sampling devices used was the Source Assessment Sampling System (SASS). This device collected particulates in four size classifications: 0.1-1 μm (micrometers aerodynamic diameter), 1-3 μm, 3-10 μm, and 10 μm Sampling was performed isokinetically at a single traverse point at the average gas velocity.

The second particulate sampling devise was an EPA-method 1 through 5 particulate sampling train. This device determined the particulate loading at the sampling point. Sampling was performed isokinetically at four traverse points.

At sample point 7, scrubber water samples were collected every other hour. Those taken before 21:00 on August 29th were taken from the bottom of the scrubber collection tank and contain

* Trade name; use of trade names does not indicate USEPA endorsement.

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FIGURE 4

RABBLE TOOTH PATTERN

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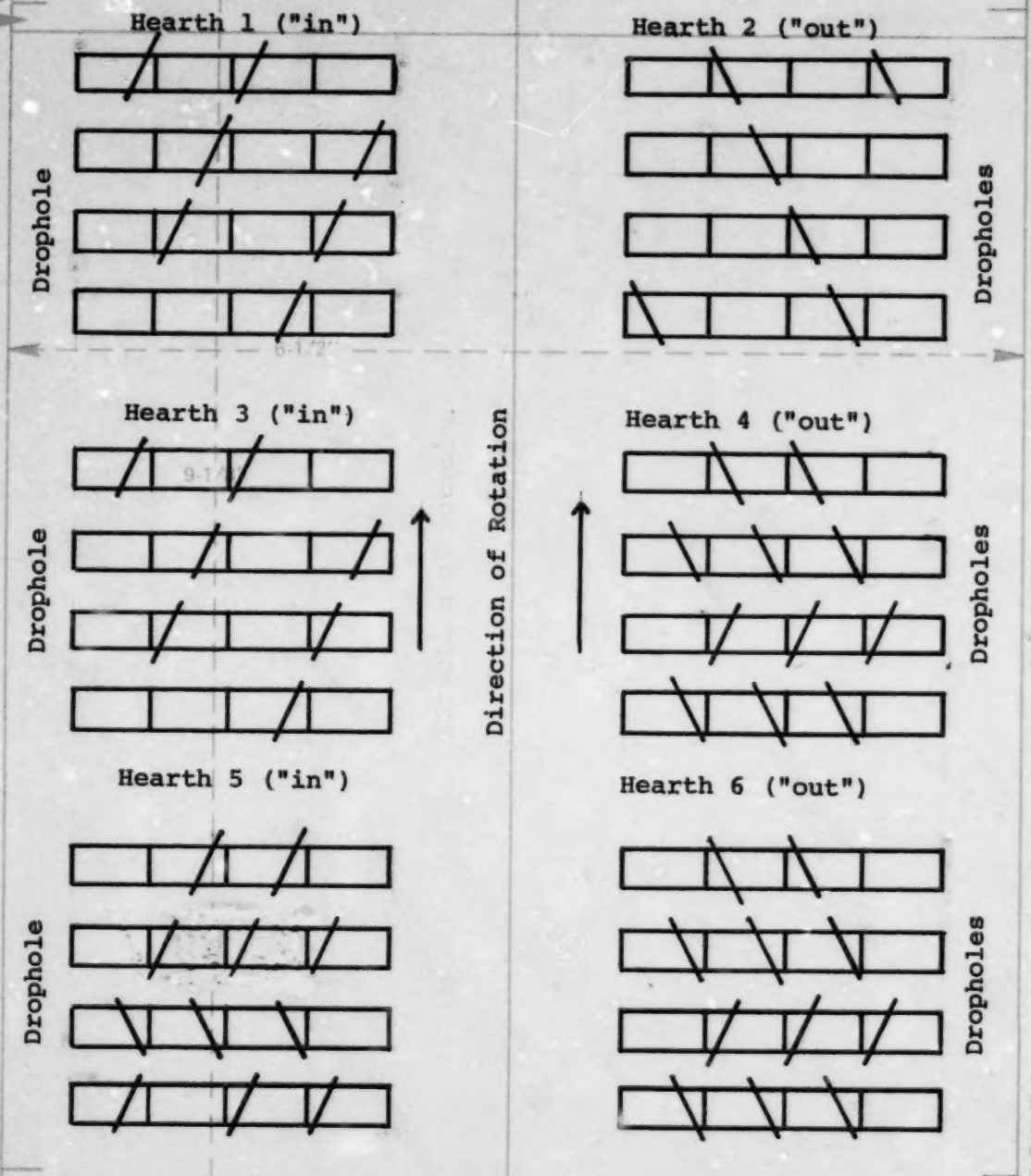

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some accumulated sediment. Those taken subsequently are representative samples of the scrubber outflow. The influent tap water was also sampled (point 8).

Measurements of Filter Cake and Furnace Residue

Composite samples of feed (sample point 2) and product (sample point 4) were analyzed for carbon, hydrogen, nitrogen, sulfur, and ash in ultimate analyses and for moisture, volatiles, ash, and fixed carbon in proximate analyses. Results are in Tables 2 through 5. See Appendix A for details of these analytical methods.

Tables 2 and 3 show that the feed compositions throughout the program were fairly consistent.

Tables 4 and 5 show that the solid product compositions were consistent within their respective modes of operation.

Furnace Modes of Operation

The furnace operated during the week of August 28 - September 1, 1978. The week was divided into four operating periods, with one on each of four days, as follows: A blank run (BLANK), an incineration (INC), a low temperature thermal conversion (LTC), and a high temperature thermal conversion (HTC). Steady state periods of 8-17 hours duration were chosen from each of these operating modes.

A blank (zero feed) run was made on August 28th. Operating conditions were as shown on Figure 5 with 820 C (1500 F) maximum temperature in the furnace and 870 C (1600 F) in the afterburner. 45.3 kg/hr (100 lb/hr) of steam were added to more closely simulate a typical furnace atmosphere.

Furnace and afterburner cooling losses were calculated from the operating conditions. See the section on mass and energy balance for further details.

Particulate sampling was performed at sample Point 6 beyond the afterburner exit to determine background loadings. The EPA-5 sampling train collected 5.7 mg/dry nm^3 (0.0025 gr/dscf.). The SASS train captured 112 mg/dry nm^3 (0.049 gr/dscf). These unabated particulate loadings were not considered significant when compared with loadings determined later in the week. There is no obvious explanation for the large difference in the two values. Particulates captured during the BLANK mode are very finely divided. The particulate size distribution shown in Figure 6 has 74% of particulates less than 0.1 μm. See also Table 6.

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TABLE 2

FILTER CAKE PROXIMATE ANALYSES

(sample point 2)

DATE & TIME	% TS	DRY BASIS		
		% VOLS.	% ASH	%F.C.
8/29-8-13:00	46.2	51.0	39.3	9.7
18-24:00	50.3	53.4,48.8	38.2,47.7	8.4,3.5
19-20:00	48.1	51.2	40.0	8.8
8/30 - 6-12:00	52.9	52.9	37.9	9.2
12-19:00	49.8			
17-24:00	52.6	52.1,51.5	38.2,39.1	9.7,9.4
8/31 - 11-17:30	55.2	51.8	38.2	10.0
17:00	51.6	49.3	46.3	4.4

TABLE 3

FILTER CAKE ULTIMATE ANALYSES

(sample point 2)

DATE & TIME	%C	%H	%N	% ASH	%S	%Cl
8/29 - 8-13:00	34.55	4.69	1.96	40.76	1.27	
18-24:00	36.76	4.94	1.94	43.23	1.52	
	35.50	5.03	1.70	41.76	1.77	0.36
19-20:00	33.78	4.76	1.96	41.64	1.69	
8/30 - 6-12:00	37.88	5.35	1.96	41.18	1.38	
12-19:00	36.09	5.10	1.77	41.21	1.54	
17-24:00	38.35	5.13	1.19	40.13	1.66	0.35
	35.95	5.26	1.67	39.02	1.44	0.40
8/31 11-17:30	36.71	5.54	2.05	39.07	1.32	
17:00	37.46	5.50	1.89	41.38	1.49	

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TABLE 4

FURNACE RESIDUE PROXIMATE ANALYSES

(sample point 4)

DATE & TIME		% TS	DRY BASIS % VOLS.	DRY BASIS % ASH	DRY BASIS %FC
8/29-	11-14:00	100	5.8	91.2	3.0
	15-23:00		4.2,3.3	95.0,95.1	0.8,1.6
8/30-	6,9-12:00		5.7	84.9	9.4
	14-17:00		5.2	81.3	13.5
	19-20,23:00		5.0,5.8	81.9,80.5	13.1,13.7
8/31-	12,13,15-17:00		2.8	88.3	8.9

6-1/2"

TABLE 5

FURNACE RESIDUE ULTIMATE ANALYSES

(sample point 4)

9-1/8"

DATE & TIME		%C	%H	%N	%ASH	%S	%Cl
8/29-	11-14:00	5.85	0.25	0.014	91.48	1.82	
	15-23:00	4.23	0.20	0.92**	95.72	1.79	0.27
		4.93	0.24	0.007	91.18	1.60	
8/30-	6,9-12:00	13.27	0.45	0.035	82.72	1.92	
	14-17:00	15.34	0.37	0.049	83.02	2.18	
	19-20-23:00	15.27	0.62	5.74**	82.05	1.95	0.43
8/31-	12,13,15-17:00	7.90	0.13	1.49**	90.41	1.69	

** Probably x100 too large

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FIGURE 5

FURNACE RUN SUMMARY SHEET

RUN DESIGNATION: BLANK

DATE: 8/28-8/24/78
TIME: 17:00-0030

FEED 0
Total
Water
Solids
Ash
Vol.
FC
HV.

868 ± 9 C

AFTERBURNER
232.6 kg/hr air
8.69 ∓ .40 kg/hr nat. gas

Flows in kg/hr

		Air	Nat. gas	Steam
1	609 ∓ 6 C	0	0	
2	719 ∓ 6 C	0	0	
3	771 ∓ 5 C	0	4.56 ∓ .05	
4	821 ∓ 5 C	72.7 ∓ 0	0	45.4
5	637 ∓ 18 C	0	3.16 ∓ .11	
6	762 ∓ 10 C	51.9 ∓ 1.9	0	

RPM

PRODUCT 0
Total
Ash
Vol.
FC
HV.

REMARKS: SASS run 1, 1656-1955; EPA-5 run 1 at 2130.

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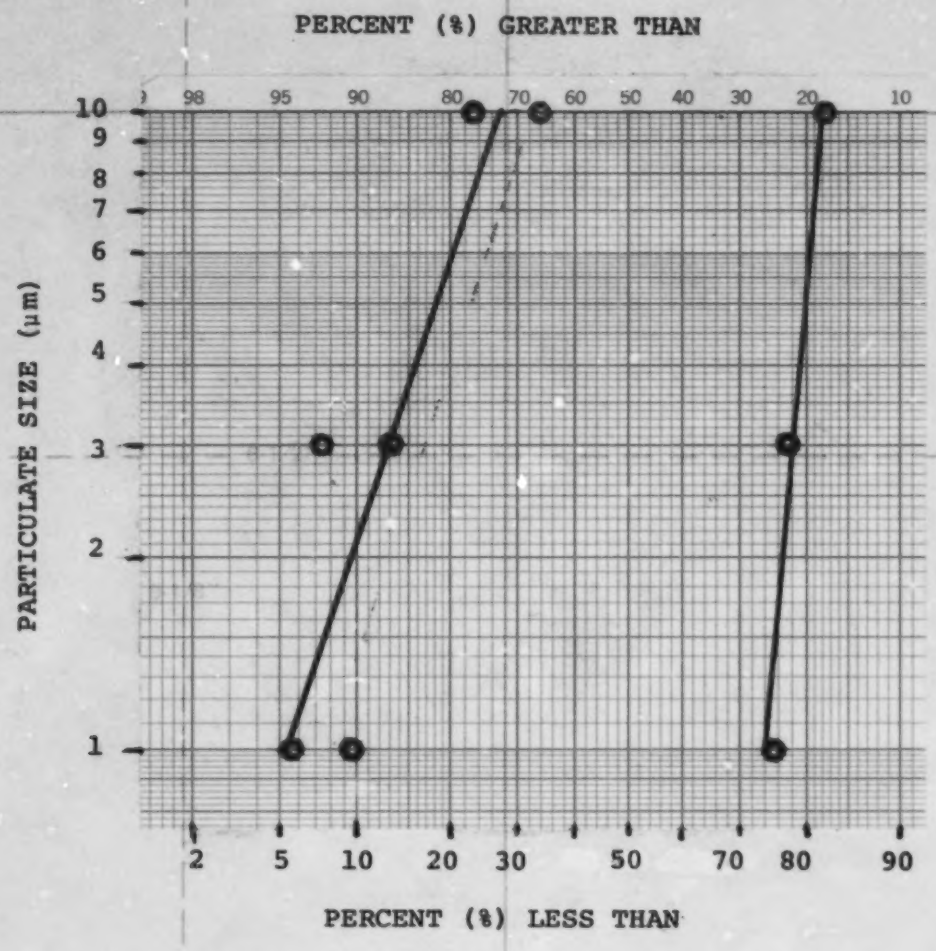

FIGURE 6
PARTICULATE EMISSIONS SIZE DISTRIBUTION
SASS RUN 2 & 3 - 8/29/78
INC MODE
SASS RUN 1 - 8/28/79
BLANK MODE

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TABLE 6

Date: 8/28/78
Time: 1656-1955
Mode: BLANK

PERCENT HEAVY METALS IN PARTICULATE CATCHES

SASS RUN 1

ELEMENT	---------PARTICULATE SIZE FRACTION (MICRONS)------ >10	10-3	3-1	0.1-1
AG	0.001074	0.0	0.0	0.001207
AL	1.435299	12.534883	2.563572	0.0
AS	0.013599	0.126246	0.009164	0.000393
B	0.037317	0.0	0.0	0.0
BA	0.063856	1.242524	0.194273	0.000026
BE	0.000007	0.0	0.006644	0.0
CA	0.955983	0.0	0.0	0.0
CD	0.019983	0.0	0.009393	0.000241
CO	0.066583	0.171429	0.015693	0.000265
CR	1.933473	9.215945	0.674685	0.004612
CU	0.083746	0.0	0.058419	0.001233
FE	16.519028	96.744843	7.608246	0.022532
HG	0.000021	0.0	0.0	0.000098
MG	0.502262	3.831228	0.564719	0.0
MN	0.108589	0.443521	0.084765	0.003293
MO	0.033231	0.0	0.0	0.001125
NA	0.030561	0.0	0.0	0.0
NI	0.643029	0.0	0.0	0.003480
P	0.213799	0.0	0.0	0.0
PB	0.113412	0.0	0.0	0.001556
SB	0.065975	0.0	0.012715	0.000765
SE	0.002147	0.001993	0.0	0.003140
SI	0.267821	6.845846	1.957617	0.031482
SN	0.001610	0.0	0.0	0.000251
SR	0.008045	0.0	0.0	0.0
TI	0.083252	0.893688	0.169530	0.000628
TL	0.0	0.0	0.0	0.0
V	0.024141	0.034551	0.017182	0.0
ZN	0.753113	0.0	0.0	0.012718
TOTAL	23.980835	132.086639	13.946611	0.089046

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An extrapolation of the plot would predict an average particle size of 0.01 μm The 0.01-1 μm size fraction (see Table 2) is low in heavy metals (totaling 0.08%). The 3-10 and larger than 10 μm size fractions have a high iron content which could be stray particles of rust.

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Introduction to Incineration Mode (INC)

The INC mode (Figure 7) was run on August 29th from 09:30 to 23:00 hours. It had a maximum temperature of 900 C (1650 F) on hearth 2. The temperature was successively lower on each hearth from 3 to 6, and it was 524 C (975 F) on hearth 6. Ninety six percent (96%) excess air was added to the furnace. The gas flow pattern was updraft to Hearth 1. Fuel was required only in the afterburner.

Mass and Energy Balances for INC Mode

Mass and energy in and out of the system for the INC mode are summarized in Table 7. The degree of accuracy of the balances is discussed in the summary section below.

INC Mode Residue

The INC mode residue is ash. The carbon in the devolatilized char of the top furnace hearths has been combusted in direct contact with oxygen in an exothermic reaction in the lower hearths of the furnace.

The heating value of the ash could not be determined by bomb calorimetry as the samples would not ignite. The heating value can be estimated from the ultimate analysis, however. The calculated higher heating value averages $1.9 \times 10^6 \pm 0.3 \times 10^6$ joules/kg (810 ± 130 BTU/lb). (The method for heating value calculation is in Appendix A).

The average proximate analysis of the ash is 4.4% volatiles, 93.8% ash, and 1.8% fixed carbon. This is a somewhat high organics content for incineration ash.

The average ultimate analysis of the product is: 5.0% carbon, 0.23% hydrogen, 0.01% nitrogen, 1.[illegible]% sulfur, 0.27% chloride and 92.8% ash.

Particulates from INC Mode

The three determinations of unabated particulate emissions at Point 6 are listed in Table 8. The first value is much less than the other two values but the overall average is 1.5 ± 0.7 kg/hr.

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FIGURE 7

FURNACE RUN SUMMARY SHEET

RUN DESIGNATION: INC

DATE: 8/29/79
TIME: 0930-2300

FEED (kg/hr)
Total 113.4
Water 58.7
Solids 54.7
Ash 22.5
Vol. 27.9
FC 4.3
HV 18.9 MJ/kg dry
(8123 BTU/lb)

912 ± 37°C

AFTERBURNER
243.0 kg/hr air
4.24 ± 1.44 kg/hr nat. gas

		Flows in kg/hr.		
		Air	Nat. gas	Steam
1	744 ± 38°C	0	0	
2	90 ± 27°C	47.8 ± 0	0	
3	870 ± 39°C	200.4 ± 3.1	0	
4	737 ± 24°C	64.4 ± .8	0	
5	627 ± 27°C	82.9 ± .6	0	
6	524 ± 22°C	57.9 ± 16.6	0	

0.33 RPM

PRODUCT (kg/hr)
Total 20.1
Ash 18.9
Vol. 0.9
FC 0.4
HV. *

REMARKS: SASS runs 1 and 2, -1045-1350 and 1800-1925; EPA-5s at 1500 and 2210

* Product samples would not ignite in Paar bomb.

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TABLE 7

MASS & ENERGY BALANCES

INC MODE

	LEAK
O	
N	
TOTAL	0
ENTHALPY	

	AIR	FUEL
C	0	3.08
H	0	0.99
O	55.5	0.07
N	182.7	0.03
TOTAL	238.2	4.16
ENTHALPY	0	214.9

AFTER-BURNER

	EXHAUST
C	21.3
H	10.1
O	219.8
N	524.6
S	0.5
ASH	1.8
TOTAL	778.1
ENTHALPY	1056.4

	GAS ANALYSES CALC.	GAS ANALYSES MEASURED
H_2O	18.0%	22.6%
CO_2	7.7	-
O_2	11.1	9.5
N_2	81.2	-
SO_2	0.068	0.043

wet

dry basis

AB R & C = 98.7

	AIR	FUEL	FEED WATER	FEED SOLIDS
C	0		0	19.2
H	0		6.51	2.7
O	103.6		52.16	8.5
N	340.0		0	1.0
S	0		0	0.9
ASH	0		0	22.5
TOTAL	444.4	0	58.69	54.7
ENTHALPY	0	0	0	1032.5

MHF

	PRODUCT
	1.0
	0.04
	0
	0.002
	0.3
	18.7
	20.1
	48.6

ENTHALPIES IN MJ/hr
FLOWS IN kg/hr.

FURNACE R & C
LOSS = 209.4

TOTAL IN 800.2 kg/hr 1247.4 MJ/hr

TOTAL OUT 798.2 kg/hr 1413.1 MJ/hr

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This translates to 28 ± 12.5 gm/kg dry solids fed. The particulate loading was 2500 ± 1100 mg/dnm^3 (1.1 ± 0.5 gr/dscf).

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The log-normal plot of particulate size distribution determined from SASS data is shown in Figure 6. Ninety-five percent of the particulates captured (by weight) are larger than 1 μm. An average particulate size of 40 μm can be estimated by extrapolation.

The heavy metals assays of the SASS particulate catches are in Tables 9 and 10. It is most notable that the 0.1 - 1 μm catch contains a smaller fraction of heavy metals than the coarser particulate catches. Also, the 1-3 μm catch contains a higher

TABLE 8. COMPARISON OF PARTICULATE EMISSION DATA
LOCATION: SAMPLE POINT 6 BETWEEN SCRUBBER AND AFTERBURNER

MODE	DATE	TIME	MASS RATE EPA-5 kg/hr	MASS RATE SASS kg/hr	MASS ON DRY FEED BASIS gm/kg feed
BLANK	8/28	1656-1955		0.055	-
		2130-2200	0.0034		-
INC	8/29	1045-1350		0.726	13.3
		1500-1520	1.99		36.4
		1800-1925		1.85	33.9
LTC	8/30	1230-1435		0.812	13.9
		1645-1750		0.889	15.2
	8/31	0000-0100	0.84		14.3
HTC	8/31	1118-1218		1.33	22.1
		1415-1525		0.875	14.5
		1636-1736	1.07		17.7

proportion of metals measured. The exceptions to this general trend are Ag, As, Cd, Cu, Mo, Pb, Se, Tl and Zn; these metals have similar or higher concentrations in the finest size fraction.

Data in tables 11 and 12 complement the information in previous tables. These tables contain the relative distribution of each metal among the particulate size fractions independent of its absolute concentration. These tables show that most metals are concentrated in the coarser particulate size fractions.

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Metals Account During INC Mode

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Tables 13 through 15 show the heavy metals balance from

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TABLE 9

DATE: 8/29/78
TIME: 1045-1350
MODE: INC

PERCENT HEAVY METALS IN PARTICULATE CATCHES

SASS RUN 2

	---------PARTICULATE SIZE FRACTION (MICRONS)------			
ELEMENT	>10	10-3	3-1	0.1-1
AG	0.002988	0.007520	0.012444	0.001776
AL	2.362158	2.612022	2.090103	0.018559
AS	0.017342	0.023609	0.060458	0.031884
B	0.020632	0.015475	0.009796	0.000325
BA	0.082991	0.007840	0.009492	0.003366
BE	0.000142	0.000163	0.000170	0.000033
CA	4.249169	1.739697	6.553842	0.043617
CD	0.046263	0.042421	0.115476	0.106569
CO	0.024173	0.018015	0.013461	0.000919
CR	0.192145	0.249552	0.308199	0.058512
CU	0.233504	0.344708	0.475664	0.320928
FE	4.955570	5.176353	5.965539	0.377611
HG	0.000030	0.000056	0.000039	0.0
MG	1.040837	0.972435	0.992814	0.007344
MN	0.046313	0.056237	0.054705	0.005714
MO	0.013226	0.015889	0.019731	0.054919
NA	0.672697	0.925579	0.865481	0.220189
NI	0.066713	0.095090	0.107975	0.046292
P	1.559820	0.758932	0.620908	0.217200
PB	0.709496	1.310322	3.281698	5.866809
SB	0.025228	0.032445	0.037219	0.015396
SE	0.000443	0.000089	0.001194	0.002159
SI	0.078832	0.017041	0.036519	0.009773
SN	0.030859	0.005127	0.001993	0.045404
SR	0.018754	0.021065	0.014676	0.000275
TI	0.040332	0.000831	0.003542	0.003012
TL	0.0	0.000591	0.001866	0.005051
V	0.032831	0.036835	0.034116	0.003440
ZN	1.186840	2.128141	3.097626	1.358083
TOTAL	17.710266	16.614059	24.786652	8.825153

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TABLE 10

DATE: 8/29/78

TIME: 1800-1925

MODE: INC

PERCENT HEAVY METALS IN PARTICULATE CATCHES

SASS RUN 3

ELEMENT	>10	10-3	3-1	0.1-1
	---------PARTICULATE SIZE FRACTION (MICRONS)------			
AG	0.009559	0.008590	0.013387	0.002027
AL	2.394471	2.769923	2.291761	0.0
AS	0.015324	0.020688	0.046953	0.016123
B	0.020049	0.019408	0.019549	0.0
BA	0.083329	0.005144	0.068530	0.002437
BE	0.000145	0.000165	0.000122	0.000021
CA	5.400702	1.814700	9.201653	0.0
CD	0.017589	0.033385	0.088605	0.064968
CO	0.023980	0.021102	0.027503	0.008627
CR	0.159906	0.207075	0.276875	0.200551
CU	0.267370	0.411137	0.572954	0.279712
FE	6.159318	4.433025	7.889967	1.103368
HG	0.000209	0.000230	0.000077	0.0
MG	1.229324	1.023575	1.359674	0.0
MN	0.051366	0.061615	0.007427	0.024197
MO	0.012245	0.017003	0.027160	0.069526
NA	0.672087	0.957596	0.919178	0.0
NI	0.071497	0.111085	0.150658	0.176930
P	1.578391	1.077968	1.618399	0.126714
PB	0.582846	0.768720	2.777942	3.911075
SB	0.021655	0.032099	0.027224	0.014766
SE	0.000443	0.000127	0.001008	0.002947
SI	0.104988	0.053518	0.062570	0.005252
SN	0.028547	0.006167	0.004993	0.036090
SR	0.017816	0.022896	0.026133	0.000329
TI	0.072096	0.002786	0.002288	0.001293
TL	0.0	0.000302	0.0	0.004633
V	0.033810	0.039734	0.040288	0.002636
ZN	1.186733	2.158839	3.222706	0.723128
TOTAL	20.215683	16.078583	30.745468	6.777341

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TABLE 11

DATE: 8/29/78

TIME: 1045-1350

MODE: INC

DIST. OF ELEMENTS AMONG PARTICULATE SIZE FRACTIONS(%)

SASS RUN 2

ELEMENT	>10	10-3	3-1	0.1-1
	---------PARTICULATE SIZE FRACTION (MICRONS)------			
AG	49.26	36.97	9.69	4.09
AL	72.86	24.02	3.04	0.08
AS	54.74	22.22	9.01	14.04
B	80.11	17.91	1.80	0.18
BA	96.23	2.71	0.52	0.54
BE	69.83	23.93	3.95	2.30
CA	83.59	10.20	6.09	0.12
CD	58.39	15.96	6.88	18.77
CO	79.76	17.72	2.10	0.42
CR	66.43	25.72	5.03	2.82
CU	57.87	25.47	5.57	11.10
FE	72.52	22.58	4.12	0.77
HG	61.61	34.55	3.84	0.0
MG	75.50	21.03	3.40	0.07
MN	69.69	25.23	3.89	1.20
MO	49.80	17.84	3.51	28.85
NA	65.94	27.05	4.00	3.01
NI	62.57	26.59	4.78	6.06
P	84.51	12.26	1.59	1.64
PB	34.21	18.84	7.47	39.48
SB	65.01	24.93	4.53	5.54
SE	53.56	3.20	6.82	36.43
SI	90.61	5.84	1.98	1.57
SN	79.50	3.94	0.24	16.32
SR	72.79	24.37	2.69	0.15
TI	97.97	0.60	0.41	1.02
TL	0.0	18.18	9.09	72.73
V	71.52	23.92	3.51	1.05
ZN	55.02	29.41	6.78	8.78

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TABLE 12

DATE: 8/29/78

TIME: 1800-1925

MODE: INC

DIST. OF ELEMENTS AMONG PARTICULATE SIZE FRACTIONS(%)

SASS RUN 3

ELEMENT	>10	10-3	3-1	0.1-1
	---------PARTICULATE SIZE FRACTION (MICRONS)------			
AG	80.73	14.86	3.27	1.14
AL	79.08	18.74	2.19	0.0
AS	69.67	19.26	6.17	4.90
B	81.54	16.17	2.30	0.0
BA	96.31	1.22	2.29	0.19
BE	78.95	18.36	1.92	0.77
CA	89.44	6.16	4.40	0.0
CD	56.14	21.82	8.17	13.86
CO	80.81	14.56	2.68	1.94
CR	71.47	18.96	3.58	5.99
CU	69.12	21.77	4.28	4.83
FE	83.58	12.32	3.09	1.00
HG	80.92	18.21	0.86	0.0
MG	83.16	14.18	2.66	0.0
MN	78.04	19.17	0.33	2.46
MO	57.87	16.46	3.71	21.97
NA	75.11	21.92	2.97	0.0
NI	64.74	20.60	3.94	10.71
P	85.12	11.91	2.52	0.46
PB	53.87	14.55	7.42	24.16
SB	72.18	21.91	2.62	3.29
SE	63.71	3.74	4.19	28.35
SI	88.89	9.28	1.53	0.30
SN	88.20	3.90	0.45	7.45
SR	76.52	20.14	3.24	0.09
TI	99.01	0.78	0.09	0.12
TL	0.0	16.67	0.0	83.33
V	78.10	18.80	2.69	0.41
ZN	67.03	24.98	5.26	2.73

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TABLE 13

HEAVY METALS BALANCES WITH SASS 2
COMBINING MONSANTO AND ISC ANALYSES

BASIS: ASH IN = ASH OUT + PARTICULATES
DATE: 8/29/78 TIME: 1045-1350 MODE: INC

METAL	MG / KG DRY SOLIDS FED			% OF FEED AC-COUNTED FOR		% UNAC-COUNTED FOR
	FEED	RESIDUE	PART.	RESIDUE	PART.	
AG	15.80	8.07	0.56	51.05	3.57	45.38
AS	0.51	3.68	2.95	725.77	581.40	*******
BE	1.98	0.81	0.02	40.74	0.95	58.31
CD	16.81	3.62	7.37	21.52	43.85	34.63
CR	479.00	524.71	26.90	109.54	5.62	-15.16
CU	1053.00	986.64	37.53	93.70	3.56	2.74
FE	21747.99	27444.31	635.46	126.19	2.92	-29.11
HG	20.82	0.21	0.00	1.00	0.02	98.98
MN	180.00	195.83	6.18	108.80	3.43	-12.23
NI	217.00	226.18	9.92	104.23	4.57	-8.80
PB	939.00	565.04	192.96	60.17	20.55	19.28
SE	0.0	0.0	0.0	0.0	0.0	0.0
V	0.0	0.0	0.0	0.0	0.0	0.0
ZN	4251.00	4277.95	200.64	100.63	4.72	-5.35

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TABLE 14

CAMPAIGN IV HEAVY METALS BALANCES WITH EPA-5 TEST 2
EMPLOYING ISC'S ANALYSES

BASIS: ASH IN = ASH OUT + PARTICULATES
DATE: 8/29/78 TIME: 1500-1520 MODE: INC

METAL	MG / KG DRY SOLIDS FED			% OF FEED ACCOUNTED FOR		% UNACCOUNTED FOR
	FEED	RESIDUE	PART.	RESIDUE	PART.	
AG	17.05	10.69	1.01	62.70	5.95	31.35
AS	0.53	6.22	5.88	******	******	*******
BE	1.89	0.81	0.0	42.61	0.0	57.39
CD	13.69	3.93	8.19	28.72	59.83	11.44
CR	549.50	387.77	46.81	70.57	8.52	20.91
CU	1117.00	898.00	70.77	80.39	6.34	13.27
FE	28904.48	26622.57	1974.97	92.11	6.83	1.06
HG	27.35	0.10	0.0	0.38	0.0	99.62
MN	199.50	197.62	16.36	99.06	8.20	-7.25
NI	250.50	230.00	17.32	91.82	6.91	1.27
PB	1018.50	468.95	206.48	46.04	20.27	33.68
SE	0.01	0.0	0.02	0.0	0.0	0.0
V	0.0	80.75	4.64	0.0	0.0	0.0
ZN	4477.00	3489.41	323.06	77.94	7.22	14.84

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TABLE 15

HEAVY METALS BALANCES WITH SASS 3
COMBINING MONSANTO AND ISC ANALYSES

BASIS: ASH IN = ASH OUT + PARTICULATES
DATE: 8/29/78 TIME: 1800-1925 MODE: INC

METAL	MG / KG DRY SOLIDS FED			% OF FEED ACCOUNTED FOR		% UNACCOUNTED FOR
	FEED	RESIDUE	PART.	RESIDUE	PART.	
AG	17.05	10.76	2.96	63.09	17.34	19.58
AS	0.53	6.26	5.49	******	******	*******
BE	1.89	0.81	0.05	42.87	2.42	54.70
CD	13.69	3.96	7.82	28.90	57.13	13.97
CR	549.50	390.14	55.86	71.00	10.17	18.83
CU	1117.00	903.51	96.58	80.89	8.65	10.47
FE	28904.48	26785.83	1839.70	92.67	6.36	0.97
HG	27.35	0.10	0.06	0.38	0.24	99.38
MN	199.50	198.83	16.43	99.66	8.24	-7.90
NI	250.50	231.41	27.57	92.38	11.01	-3.39
PB	1018.50	471.83	270.21	46.33	26.53	27.14
SE	0.0	0.0	0.0	0.0	0.0	0.0
V	0.0	0.0	0.0	0.0	0.0	0.0
ZN	4477.00	3510.81	442.02	78.42	9.87	11.71

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three time periods, during the INC mode. The constant ash basis corrects for any inaccuracy in the product weight as measured. Most metals are accounted for within ± 30%. Of these metals Cd and Pb could be said to be volatilized, with 40-60% of the feed Cd and 20-26% of the feed Pb detected in particulates. Nothing has been proven about Ag, As, Hg, Se, or V.

Measurements of Other Substances During INC Mode

NO_x - MRC data show between 0.0 and 0.02 mg/kg NO_x at sample Point 6

SO_x - MRC data show 0.27 to 2.09 gm/nm^3 as SO_2 at sample Point 6

Hydrocarbons

Hydrocarbons before the afterburner are 0.67% methane equivalent and after the afterburner are 0.085%.

Measurements taken with a portable O_2/combustibles analyzer showed that oxidizing conditions did indeed prevail on all six hearths (data in Appendix). The analyzer measured 0.4 to 2% combustibles as CH_4 on hearth 1; this is consistent with the 0.67% figure noted above.

Pesticides

There were about 2 mg/kg chlorodane and about 0.1 mg/kg dieldrin in the INC feed, but no pesticides were detectable in the residue. Exhaust gases were not checked for these substances.

Low-Temperature Thermal Converstion (LTC) Mode

The LTC mode (Figure 8) was run on August 30th. The average maximum temperature was 720 C (1330 F) on Hearth 6, but Hearths 3 through 6 were all above 700 C (1300 F) with Hearth 2 at 610 C(1130 F). The furnace air flow was 31% less than stoichiometric. The Hearth 2 burner fuel was turned on at times to maintain a minimum temperature for combustion. Fuel was also added in the afterburner. A split-draft flow pattern was used with some gas flow maintained through the Hearth 6 breeching.

Mass and Energy Balances for LTC Mode

These are summarized in Tables 16 and 17. The two tables differ in that an in-leakage of gas was assumed at the exhaust duct in Table 17. See the discussion section below for a further elaboration.

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FIGURE 8

FURNACE RUN SUMMARY SHEET

RUN DESIGNATION: LTC

DATE: 8/30-8/31/78
TIME: 0500-0030

FEED (kg/hr)
Total 113.4
Water 54.7
Solids 58.7
Ash 23.0
Vol. 30.2
FC 5.5
HV. 20.8 MJ/kgdry
or 18.8 MJ/kg
excluding sample
2-2 (8080-8933 BTU/lb)

891 ± 46°C

AFTERBURNER
243.0 kg/hr air
3.41 ± .45 kg/hr nat. gas

Flows in kg/hr

		Air	Nat. gas	Steam
1	424 ± 56°C	0	0	
2	607 ± 51°C	31.3 ± 12.0	0.83 ± 1.05	
3	714 ± 37°C	73.5 ± 23.9	0	
4	214 ± 29°C	28.0 ± 7.7	0	
5	717 ± 27°C	17.9 ± 5.8	0	
6	721 ± 24°C	12.0 ± 3.5	0	

0.33 RPM

PRODUCT (kg/hr)
Total 25.3
Ash 20.9
Vol. 1.4
FC 3.1
HV. 7.7 MJ/kg
(3327 BTU/lb)

REMARKS: SASS runs 4 and 5. 1230-1435 and 1645-1750; EPA-5 run 4 at 0000.

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TABLE 16

MASS & ENERGY BALANCES

LTC MODE

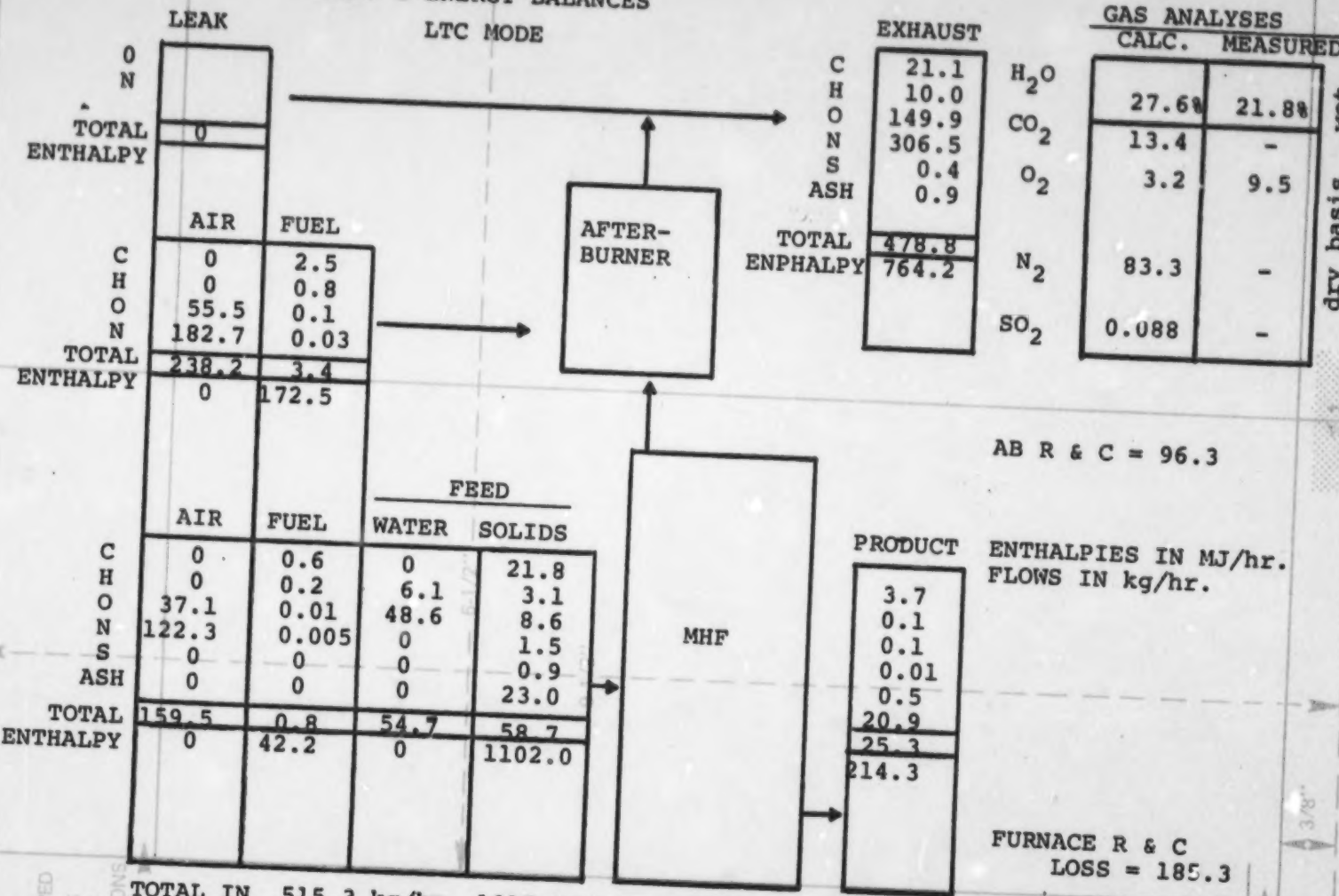
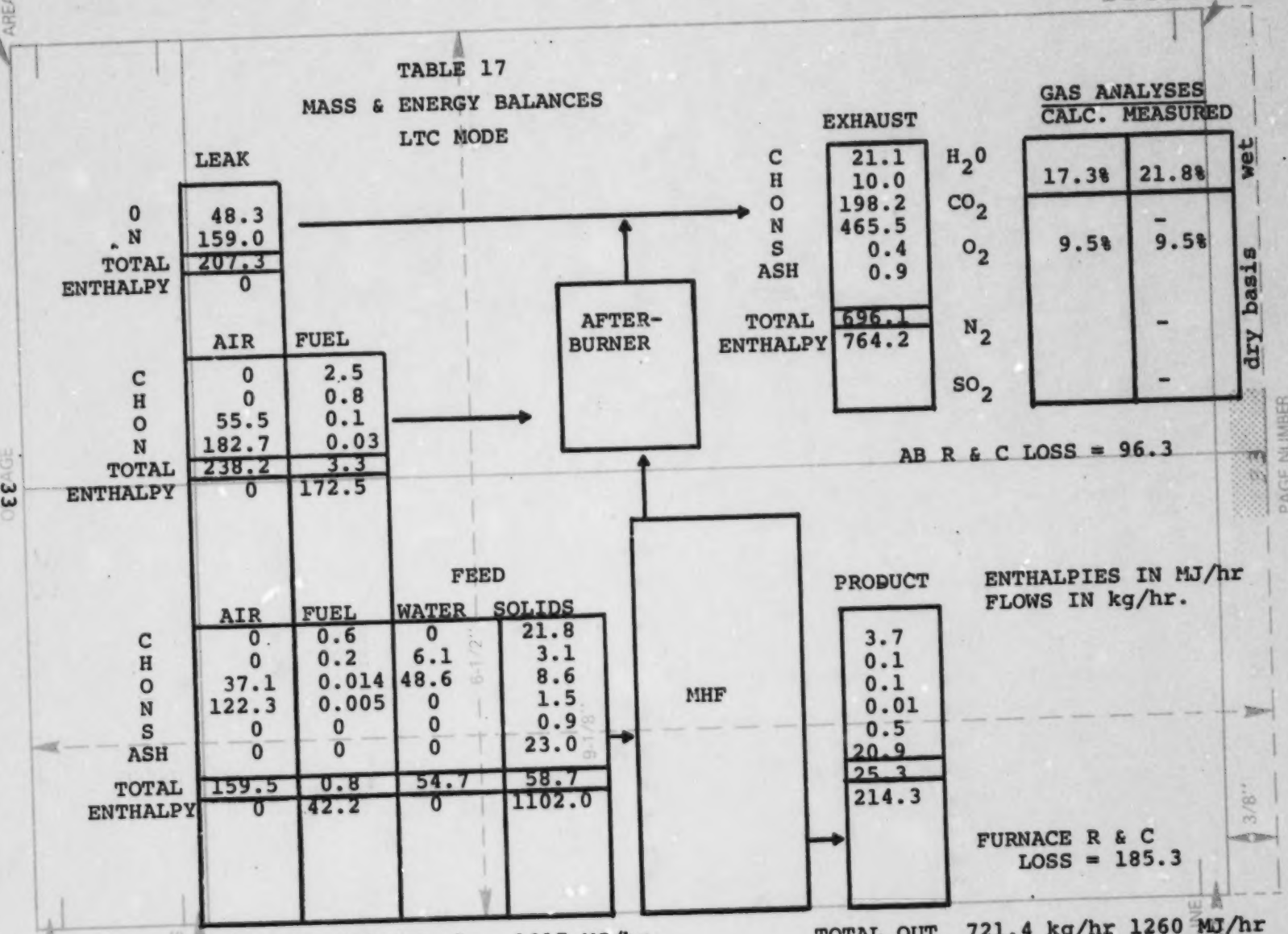


TABLE 17

MASS & ENERGY BALANCES

LTC MODE



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Residue of LTC Mode

The LTC residue consists of char with an average fixed carbon content of 12% and a volatiles content of 5%. The volatiles are somewhat low for LTC char, but in keeping with the furnace operating temperatures. The average gross heating value is 7.7 X 10^6 joules/kg (3300 BTU/lb).

The average ultimate analysis of the LTC char is 14.8% carbon, 0.45% hydrogen, 0.05% nitrogen, 82.5% ash, 2.07% sulfur, and 0.43% chloride. If volatile organics are considered to be "C_nH_{2n}" the ultimate analysis would give 12.1% fixed carbon, 3.1% volatile organics, and 1.8% unidentified volatile matter. The two analyses are consistent.

Particulates from LTC Mode

The particulate emissions rate exiting the afterburner was determined in three tests (Table 8). The average value was 0.86 + .04 kg/hr or 57.8 + 2.8 gm/kg dry solids fed. The particulate loading averaged 1.4 + 0.1 gm/nm^3 (0.060 + 0.05 gm/std ft^3) dry gas.

As shown in Figure 9, 90% (by weight) of particulates are higher than 1 μm in size. The size distribution level is lower in the 1-3 μm particulate sizes than for an ideal log-normal distribution. If the plot is extrapolated the average particle size of approximately 30 μm is obtained.

The assays of the SASS particulate catches (Tables 18 and 19) show that the finest size fraction is much lower in measured metals than the coarser size fractions. In the exceptions (Ag, Hg, Pb, Se, Si, Sn) there is a comparable percentage of metals across all size fractions. Fe and Ca concentrations peak in the 1-3 μm size fraction at 8% and 10% of the catch, respectively.

The distribution of elements among the particulate size fractions show a similar picture (Tables 20 and 21). Here the amounts of elements are weighted according to the total mass of the particulate size fractions. Most metals are concentrated in the two coarsest size fractions. The elements Ag, Mo, Ni, Se, Si, Sn have over 10% in the 0.1-1 μm fraction. Only Se is shown to be associated with the finest size fraction.

Metals Accountings During LTC Mode

Tables 22 through 24 present the heavy metals balances during three time periods of the LTC mode of operation. Arsenic (As) is over accounted for with quantities determined to be leaving the system in excess of the amount entering. Be, Cd, Cr, Cu, Fe, Mn, Ni, and Zn are all within + 30% of exact accountability. Pb just misses this criterion with 66% of feed lead

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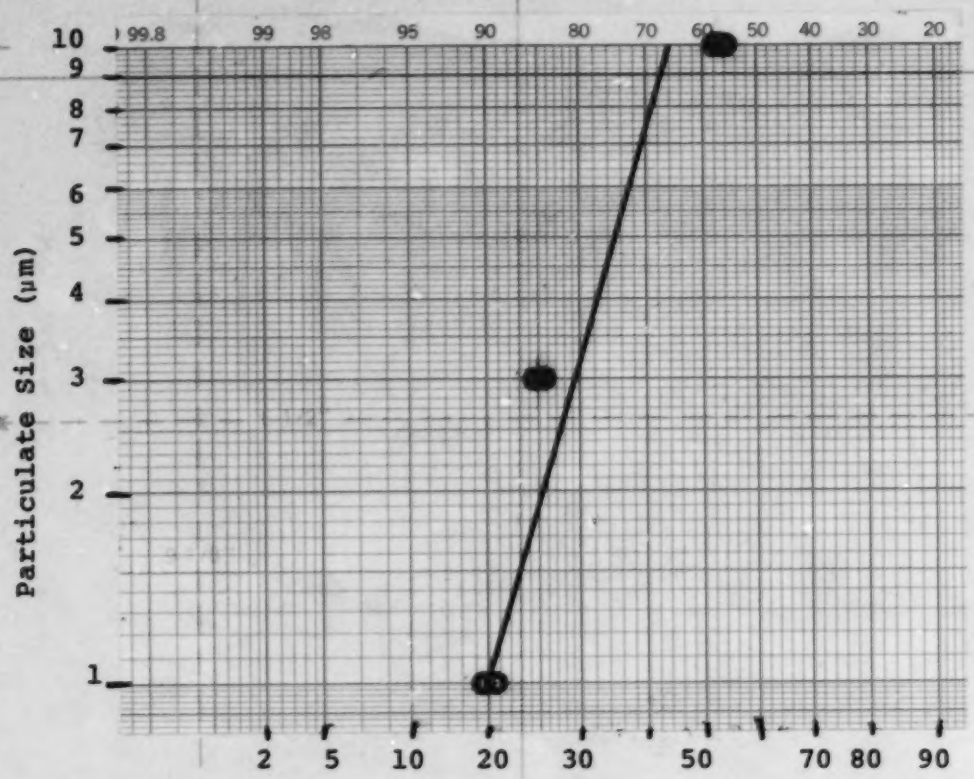
FIGURE 9



PARTICULATE EMISSIONS SIZE DISTRIBUTION

SASS RUN 4 & 5 - 8/30/78 LTC MODE

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TABLE 18

DATE: 8/30/78

TIME: 1230-1435

MODE: LTC

PERCENT HEAVY METALS IN PARTICULATE CATCHES

SASS RUN 4

ELEMENT	>10	10-3	3-1	0.1-1
	---------PARTICULATE SIZE FRACTION (MICRONS)------			
AG	0.002120	0.003784	0.008068	0.006353
AL	2.584306	3.078159	2.849976	0.000284
AS	0.006807	0.019792	0.122646	0.006368
B	0.018099	0.020792	0.025273	0.001615
BA	0.009737	0.050520	0.109948	0.003840
BE	0.000130	0.000155	0.000081	0.000006
CA	1.420324	3.133179	9.450511	0.0
CD	0.019153	0.039326	0.086803	0.015146
CO	0.017169	0.023076	0.027735	0.004835
CR	0.161112	0.212029	0.229686	0.056384
CU	0.278783	0.385341	0.539433	0.041483
FE	3.637935	5.408689	8.081867	0.595175
HG	0.000055	0.000039	0.000028	0.000039
MG	0.796506	1.395460	1.499288	0.0
MN	0.052693	0.063080	0.063219	0.013008
MO	0.010990	0.015667	0.022795	0.017400
NA	0.725983	0.835787	0.829442	0.0
NI	0.077974	0.126209	0.093725	0.086802
P	0.902606	1.435835	2.176318	0.041010
PB	0.347148	0.639574	1.636043	0.474382
SB	0.021808	0.030449	0.033759	0.006523
SE	0.000072	0.000104	0.000310	0.002067
SI	0.032138	0.018952	0.047696	0.073319
SN	0.004777	0.005383	0.003066	0.015113
SR	0.019227	0.026361	0.031296	0.000127
TI	0.002364	0.003285	0.006969	0.001421
TL	0.0	0.0	0.0	0.0
V	0.033657	0.002881	0.046085	0.000499
ZN	1.034728	1.846574	2.852619	0.113092
TOTAL	12.218390	18.820404	30.874557	1.576286

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TABLE 19

DATE: 8/30/78

TIME: 1645-1750

MODE: LTC

PERCENT HEAVY METALS IN PARTICULATE CATCHES

SASS RUN 5

ELEMENT	>10	10-3	3-1	0.1-1
	---------PARTICULATE SIZE FRACTION (MICRONS)------			
AG	0.001832	0.003778	0.002082	0.004544
AL	2.215979	3.070222	2.910404	0.0
AS	0.009929	0.025697	0.063228	0.006544
B	0.015938	0.019575	0.018899	0.0
BA	0.017762	0.055353	0.060626	0.003313
BE	0.000129	0.000181	0.000137	0.000034
CA	1.652510	2.663122	10.225937	0.0
CD	0.011327	0.017780	0.037248	0.007816
CO	0.016694	0.022244	0.031089	0.006169
CR	0.160578	0.235897	0.303189	0.179287
CU	0.297623	0.414116	0.580859	0.052678
FE	3.917633	5.023800	8.715386	0.929348
HG	0.000084	0.000060	0.000150	0.000110
MG	0.430424	1.233788	1.212005	0.000227
MN	0.051071	0.061055	0.069608	0.020598
MO	0.010898	0.017237	0.029190	0.029613
NA	0.695701	0.877033	0.709423	0.0
NI	0.071814	0.129385	0.149847	0.150059
P	1.019264	1.392363	2.352940	0.054381
PB	0.265119	0.441749	0.868581	0.292629
SB	0.021271	0.032973	0.031302	0.006696
SE	0.000080	0.000330	0.000801	0.002204
SI	0.288937	0.035268	0.009069	0.023611
SN	0.004046	0.014517	0.031051	0.015606
SR	0.018686	0.025847	0.028876	0.000231
TI	0.002024	0.017349	0.065079	0.001540
TL	0.0	0.0	0.0	0.0
V	0.028585	0.038871	0.039992	0.001302
ZN	0.191245	1.698586	2.688492	0.128861
TOTAL	11.417170	17.568161	31.235352	1.917396

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TABLE 20

DATE: 8/30/78

TIME: 1230-1435

MODE: LTC

DIST. OF ELEMENTS AMONG PARTICULATE SIZE FRACTIONS(%)

SASS RUN 4

ELEMENT	>10	10-3	3-1	0.1-1
	---------PARTICULATE SIZE FRACTION (MICRONS)------			
AG	37.20	30.93	11.03	20.83
AL	60.94	33.82	5.24	0.00
AS	25.42	34.44	35.70	4.44
B	60.22	32.23	6.55	1.00
BA	22.88	55.30	20.13	1.69
BE	62.00	34.44	2.99	0.57
CA	39.27	40.36	20.37	0.0
CD	40.69	38.92	14.37	6.01
CO	55.41	34.70	6.98	2.92
CR	55.88	34.26	6.21	3.65
CU	54.87	35.33	8.27	1.53
FE	52.73	36.53	9.13	1.61
HG	66.47	22.16	2.62	8.75
MG	50.94	41.58	7.47	0.0
MN	58.92	32.86	5.51	2.72
MO	47.13	31.30	7.62	13.94
NA	61.52	33.00	5.48	0.0
NI	48.64	36.68	4.56	10.12
P	51.61	38.25	9.70	0.44
PB	40.31	34.60	14.80	10.29
SB	54.73	35.60	6.60	3.06
SE	13.64	9.09	4.55	72.73
SI	55.04	15.12	6.37	23.47
SN	46.16	24.24	2.31	27.29
SR	56.60	36.15	7.18	0.07
TI	50.27	32.54	11.55	5.65
TL	0.0	0.0	0.0	0.0
V	87.01	3.47	9.28	0.24
ZN	48.39	40.23	10.40	0.99

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TABLE 21

DATE: 8/30/78

TIME: 1645-1750

MODE: LTC

DIST. OF ELEMENTS AMONG PARTICULATE SIZE FRACTIONS(%)

SASS RUN 5

ELEMENT	>10	10-3	3-1	0.1-1
	---------PARTICULATE SIZE FRACTION (MICRONS)------			
AG	38.70	41.23	4.63	15.44
AL	53.94	38.61	7.45	0.0
AS	32.13	42.95	21.51	3.41
B	56.84	36.07	7.09	0.0
BA	33.34	53.69	11.97	1.00
BE	53.06	38.70	5.95	2.29
CA	40.27	33.53	26.20	0.0
CD	44.10	35.76	15.25	4.89
CO	51.45	35.42	10.08	3.06
CR	46.79	35.51	9.29	8.40
CU	51.21	36.82	10.51	1.46
FE	51.69	34.25	12.09	1.97
HG	56.44	20.96	10.63	11.98
MG	36.01	53.33	10.66	0.00
MN	54.77	33.83	7.85	3.55
MO	39.43	32.22	11.11	17.24
NA	56.87	37.04	6.10	0.0
NI	40.22	37.44	8.83	13.52
P	51.10	36.06	12.40	0.44
PB	41.96	36.13	14.46	7.45
SB	49.84	39.92	7.71	2.52
SE	11.58	24.76	12.22	51.45
SI	92.63	5.84	0.31	1.22
SN	23.36	43.30	18.85	14.49
SR	53.22	38.03	8.65	0.11
TI	11.19	49.58	37.86	1.37
TL	0.0	0.0	0.0	0.0
V	53.85	37.83	7.92	0.39
ZN	13.94	63.95	20.60	1.51

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TABLE 22

HEAVY METALS BALANCES WITH SASS 4
COMBINING MONSANTO AND ISC ANALYSES

BASIS: ASH IN = ASH OUT + PARTICULATES
DATE: 8/30/78 TIME: 1230-1435 MODE: LTC

METAL	MG / KG DRY SOLIDS FED			% OF FEED ACCOUNTED FOR		% UNACCOUNTED FOR
	FEED	RESIDUE	PART.	RESIDUE	PART.	
AG	14.70	2.37	0.47	16.11	3.23	80.66
AS	1.26	1.48	2.23	116.99	176.53	-193.53
BE	0.98	0.94	0.02	96.16	1.79	2.06
CD	9.80	5.17	3.92	52.76	40.00	7.23
CR	539.00	383.70	24.01	71.19	4.45	24.36
CU	1024.00	758.23	42.30	74.05	4.13	21.82
FE	23835.98	26392.00	574.41	110.72	2.41	-13.13
HG	15.34	0.11	0.01	0.70	0.04	99.25
MN	230.00	181.22	7.45	78.79	3.24	17.97
NI	225.00	249.84	13.35	111.04	5.93	-16.97
PB	931.00	541.73	71.74	58.19	7.71	34.11
SE	0.0	0.0	0.0	0.0	0.0	0.0
V	0.0	0.0	0.0	0.0	0.0	0.0
ZN	4166.00	3485.72	178.06	83.67	4.27	12.06

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TABLE 23

HEAVY METALS BALANCES WITH SASS 5
COMBINING MONSANTO AND ISC ANALYSES

BASIS: ASH IN = ASH OUT + PARTICULATES
DATE: 8/30/78 TIME: 1645-1750 MODE: LTC

METAL	MG / KG DRY SOLIDS FED			% OF FEED ACCOUNTED FOR		% UNACCOUNTED FOR
	FEED	RESIDUE	PART.	RESIDUE	PART.	
AG	14.70	2.36	0.42	16.05	2.85	81.10
AS	1.26	1.47	2.74	116.58	216.41	-233.00
BE	0.98	0.94	0.02	95.82	2.19	1.99
CD	9.80	5.15	2.27	52.58	23.20	24.22
CR	539.00	382.37	30.37	70.94	5.63	23.42
CU	1024.00	755.59	51.43	73.79	5.02	21.19
FE	23835.98	26300.27	670.78	110.34	2.81	-13.15
HG	15.34	0.11	0.01	0.70	0.09	99.21
MN	230.00	180.59	8.25	78.52	3.59	17.89
NI	225.00	248.97	15.80	110.66	7.02	-17.68
PB	931.00	539.85	55.91	57.99	6.01	36.01
SE	0.0	0.0	0.0	0.0	0.0	0.0
V	0.0	0.0	0.0	0.0	0.0	0.0
ZN	4166.00	3473.60	121.44	83.38	2.92	13.71

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TABLE 24

CAMPAIGN IV HEAVY METALS BALANCES WITH EPA-5 TEST 4
EMPLOYING ISC'S ANALYSES

BASIS: ASH IN = ASH OUT + PARTICULATES
DATE: 8/31/78 TIME: 0000-0100 MODE: LTC

METAL	MG / KG DRY SOLIDS FED			% OF FEED ACCOUNTED FOR		% UNACCOUNTED FOR
	FEED	RESIDUE	PART.	RESIDUE	PART.	
AG	14.20	3.60	0.58	25.39	4.11	70.50
AS	0.09	1.95	1.93	******	******	*******
BE	0.96	0.91	0.0	93.88	0.0	6.12
CD	10.33	6.32	2.49	61.21	24.06	14.73
CR	552.50	363.22	31.02	65.74	5.61	28.65
CU	1114.50	737.69	37.00	66.19	3.32	30.49
FE	27671.96	24864.35	898.17	89.85	3.25	6.90
HG	17.16	0.10	0.0	0.59	0.0	99.41
MN	186.50	167.15	7.16	89.62	3.84	6.54
NI	231.50	189.91	11.54	82.04	4.99	12.98
PB	1025.00	616.02	64.07	60.10	6.25	33.65
SE	0.0	0.0	0.00	0.0	0.0	0.0
V	0.0	45.16	1.94	0.0	0.0	0.0
ZN	4593.50	3323.82	146.51	72.36	3.19	24.45

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accounted for in the output streams. Ag and Hg are mostly unaccounted for; Se and V are detectable in the particulates but not in the feed.

Of those metals for which a fair accountability is attained all but cadmium are retained in the product char. 23% to 40% of the Cd is incorporated into the particulate.

Measurements of Other Substances During LTC Mode

NO_2 - the average of NO_x determinations at the afterburner exit was 0.03 mg/kg.

SO_x - SO_2 data do not seem to be consistent as they showed similar mass flows of SO_2, similar volumetric flow rates 10.3 dnm^3/min or (364 dscfm) and disparate ratios of these two quantities. See Table 25.

Hydrocarbons

1.05% hydrocarbons was measured as CH_4 at the afterburner inlet. A concentration of 0.05% as CH_4 was measured in the afterburner outlet.

Oxygen

The combustible meter showed a reducing gas mixture throughout the furnace during this mode of operation. The meter showed 2-5% combustibles as CH_4 which is higher than the determination quoted above.

Pesticides

There were 1.4 mg/kg chlorodane and 0.077 mg/kg dieldrin in the LTC feed. There were no pesticides detectable in the LTC residue. Stack measurements for these compounds were not attempted.

Introduction to High-Temperature Thermal Conversion (HTC) Mode

The HTC mode (Figure 10) on August 31st was operated with a maximum temperature of 930 C (1700 F) on Hearth 4, which is close to the maximum temperature of the incineration run previously. The bottom hearths were at or above 850 C (1560 F) with Hearth 2 at 690 C (1270 F). The air admitted to the furnace was 35% less than stoichiometric. Autogenous operation was maintained in the furnace.

Mass and Energy Balances for HTC Mode

Tables 26 and 27 present mass and energy balances for this mode of operation. Table 27 differs in that an in-leakage of tramp air at the afterburner exit was assumed. See the discussion

TABLE 25. SUMMARY OF RESULTS - SULFUR DIOXIDE EMISSIONS ON THE AFTERBURNER OUTLET

Condition	Date	Run No.	Stack Volumetric Flow Rate (DSCFM)	Sulfur Dioxide Concentration lb/SCF	Sulfur Dioxide Concentration lb/hr
I	8/29/78	1	362	1.288×10^{-4}	2.796
I	8/29/78	2	362	1.70×10^{-5}	3.69×10^{-1}
II	8/30/78	3	364	2.90×10^{-5}	6.6094×10^{-1}
II	8/30/78	4	364	6.134×10^{-5}	6.361×10^{-1}
III	8/31/78	5	334	9.887×10^{-5}	1.983

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FIGURE 10
FURNACE RUN SUMMARY SHEET

RUN DESIGNATION: HTC

DATE: 8/31/78
TIME: 1100-1840

FEED (kg/hr)

Total	113.4
Water	52.8
Solids	60.6
Ash	25.6
Vol.	30.6
FC	4.4

HV. 20.7 MJ/kgdry (8889 BTU/lb)

907 ± 46°C

AFTERBURNER

243.0 kg/hr air

1.72 ± 1.48 kg/hr nat. gas

		Air	Nat. gas	Steam
1	44.9 ± 27 °C	0	0	
2	689 ± 19 °C	20.8 ± 0	0	
3	849 ± 30 °C	62.3 ± 0	0	
4	924 ± 21 °C	41.5 ± 0	0	
5	911 ± 36 °C	23.9 ± 8.7	0	
6	881 ± 33 °C	11.6 ± 3.7	0	

RPM

PRODUCT (kg/hr)

Total	25.8
Ash	22.8
Vol.	0.7
FC	2.3

HV. 5.7 MJ/kg (2446 BTU/lb)

REMARKS: SASS runs 6 and 7, 1118-1218 and 1415-1525; EPA-5 runs 5 and 6 at 1636 and 2030.

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TABLE 26

MASS & ENERGY BALANCES

HTC MODE

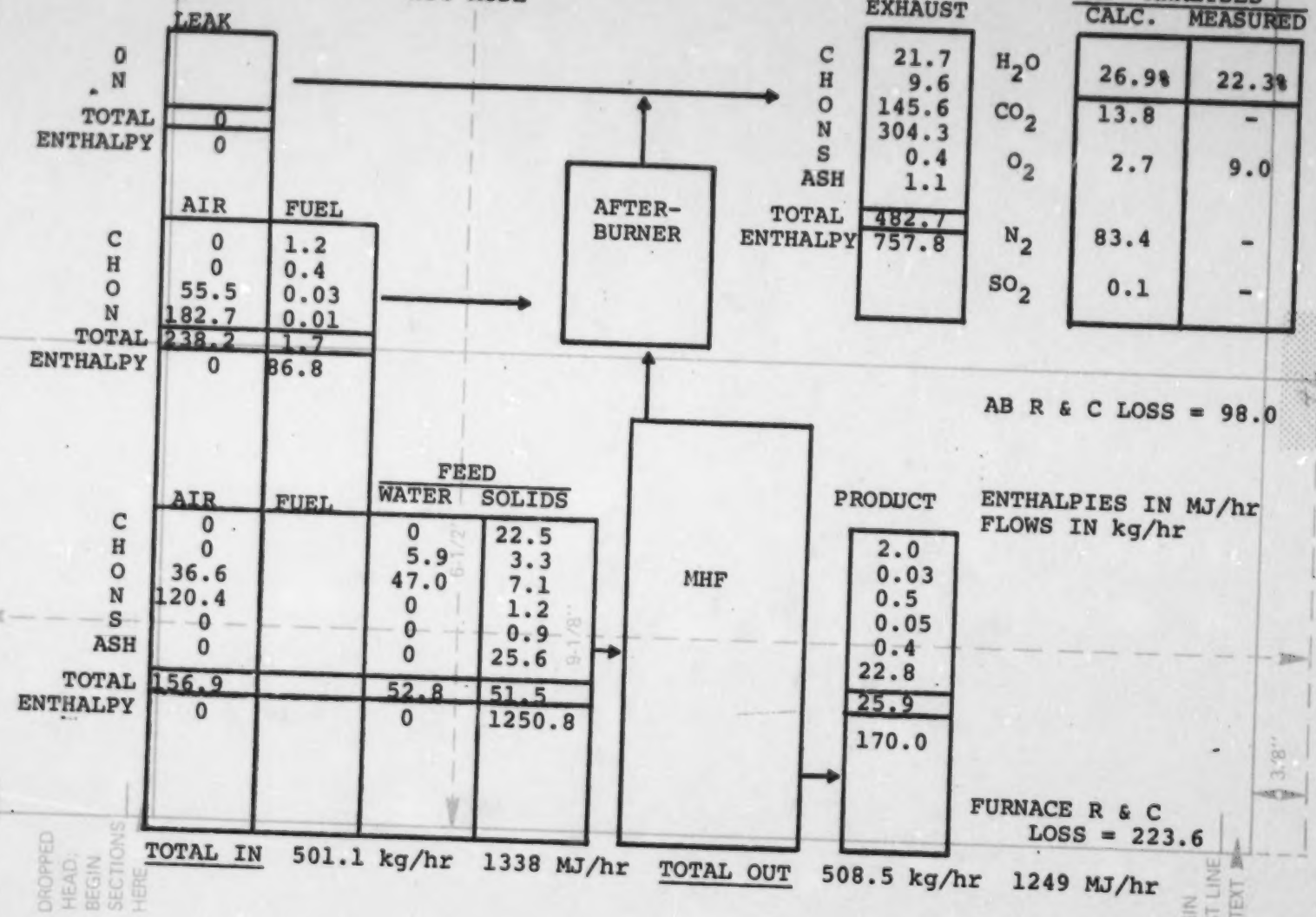
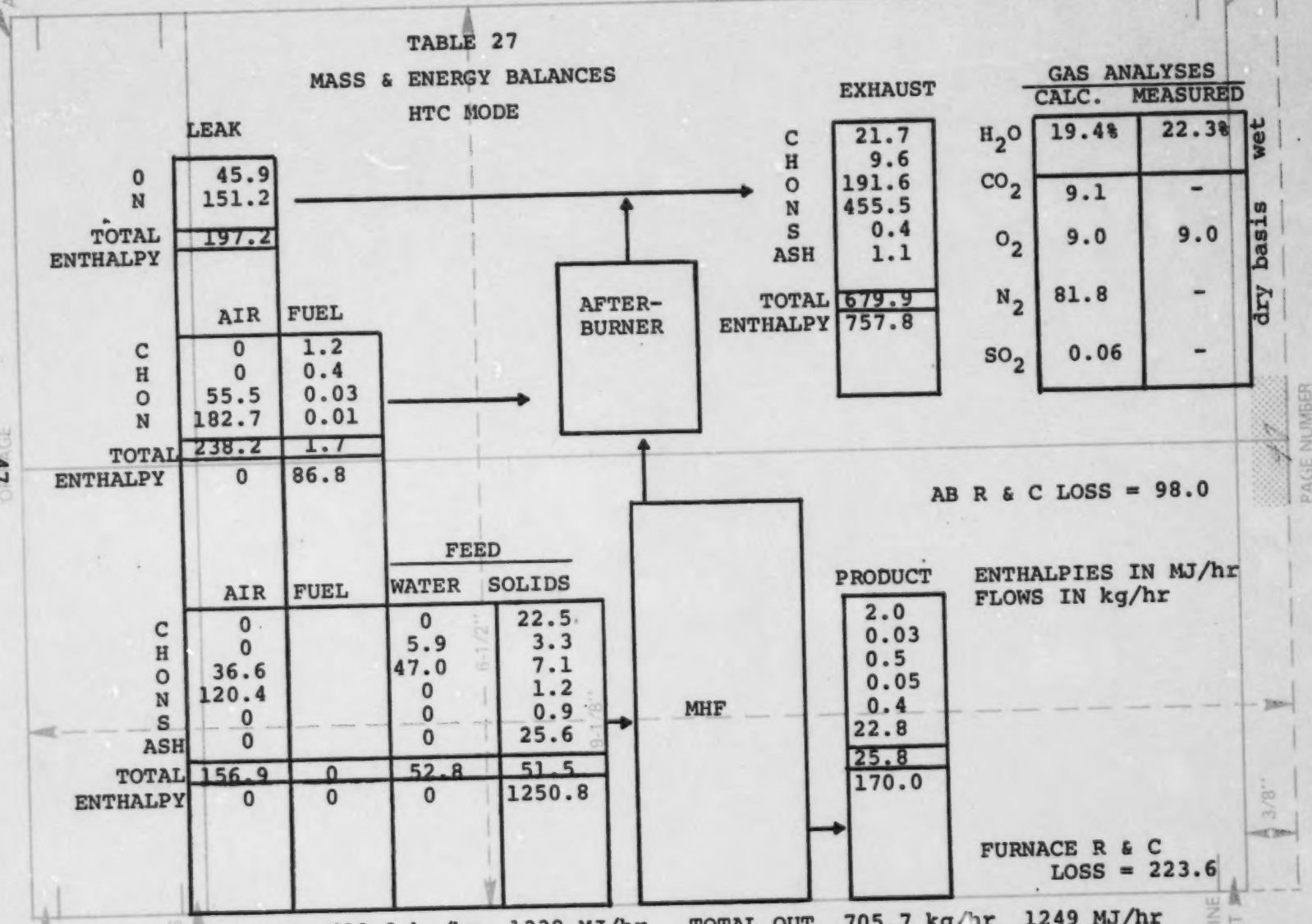


TABLE 27

MASS & ENERGY BALANCES

HTC MODE



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below for a discussion of these tables.

HTC Mode Residue

The product was char with a lower volatile and fixed carbon content than the LTC residue. There was 9% fixed carbon and 3% volatiles in the HTC residue (Table 5). The gross heating value of one composite HTC char sample was 5.69 X 10^6 joules/kg (2540 BTU/lb.).

The proximate analysis of the char sample is 2.8% volatiles, 88.3% ash, and 8.9% fixed carbon. The organics content is intermediate between that of the INC mode product and the LTC mode char.

The ultimate analysis (Table 6) of the sample is 7.9% carbon, 0.13% hydrogen, 0.015% nitrogen, 90.4% ash and 1.69% sulfur. Chlorine was not determined. The proximate analysis indicates slightly more carbon.

Particulates from HTC Mode

Three determinations of particulate from the afterburner are listed in Table 8. The average value is 1.1 ± 0.2 kg/hr. This equals 72 ± 16 gm/dry kg feed. The particulate loading averaged 13 ± 3 kg/dry nm^3 (0.93 ± 0.17 lb/dscf).

The plot of HTC particulate size distribution (Fig. 11) shows that 89% (by weight) of particulates are larger than 1,um in diameter. If the log normal plot is extrapolated an average particle size of about 100 μm is indicated.

In Tables 28 and 29 the assays of two sets of SASS catches are shown. As in the previous two cases, the finest particulates have the lowest concentrations of metals measured. Mo, Ni, Pb, Se, Si and Sn are exceptions. The 0.1 - 1 μm cut consists of 2.2% lead.

The relative distributions in Tables 30 and 31 show that, again, most metallic species are concentrated in the greater-than 3 μm particulate sizes. Ag, As, Cd, Cr, Mo, Ni, Pb, Se, Si, Sn, and Tl have greater than 10% portions present in the finest particulates.

Metals Account During HTC Mode

The metals balances for the HTC mode are in Tables 32 through 34. As for other modes of operation feed arsenic is over accounted by the product and particulate streams. Cr, Cu, Fe, Mn, Ni, and Zn are within ± 30% of being exactly accounted for. Ag, Be, Cd, and Pb are less throughly accounted for. Nearly all of the feed Hg escaped the system without detection.

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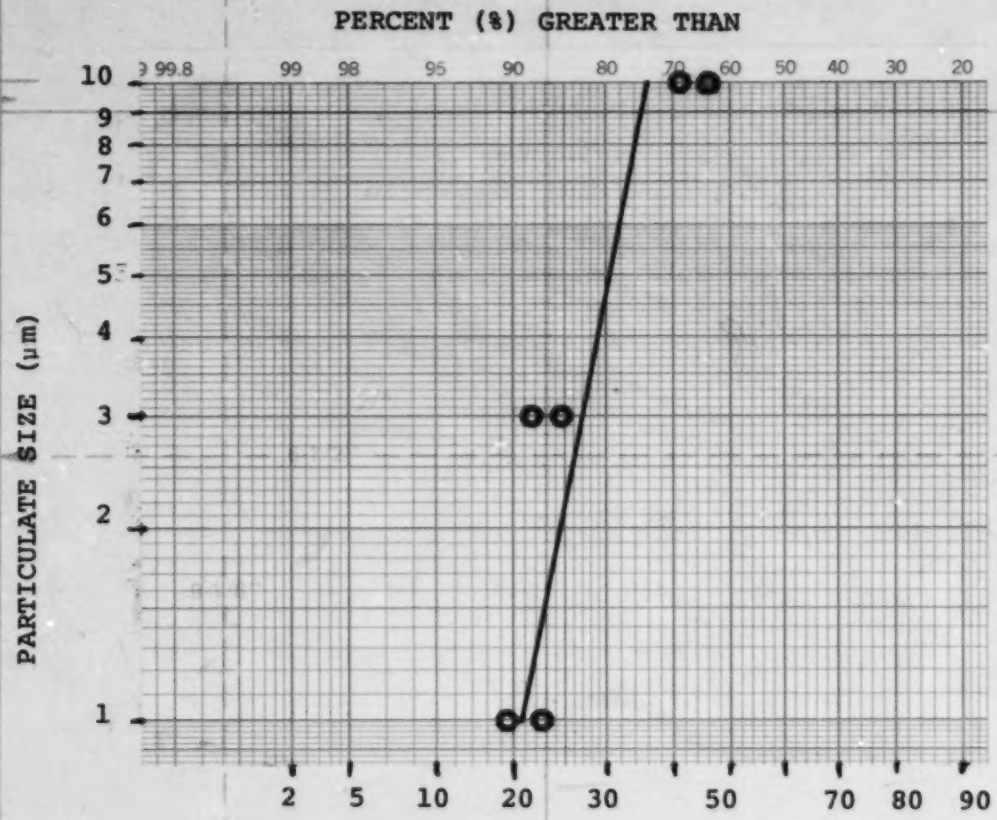
FIGURE 11



PARTICULATE SIZE DISTRIBUTION
SASS RUNS 6 & 7 - 8/31/78 HTC MODE

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TABLE 28

DATE: 8/31/78

TIME: 1118-1218

MODE: HTC

PERCENT HEAVY METALS IN PARTICULATE CATCHES

SASS RUN 6

ELEMENT	>10	10-3	3-1	0.1-1
	---------PARTICULATE SIZE FRACTION (MICRONS)------			
AG	0.001826	0.005235	0.000405	0.005512
AL	2.398135	2.677975	2.561128	0.0
AS	0.013726	0.030239	0.077670	0.022315
B	0.018716	0.021981	0.0	0.000330
BA	0.093444	0.022597	0.140574	0.001721
BE	0.000110	0.000151	0.0	0.000020
CA	4.652566	2.889232	6.439003	0.0
CD	0.022044	0.041913	0.093483	0.026420
CO	0.023399	0.028177	0.025607	0.005816
CR	0.171519	0.047132	0.233661	0.097600
CU	0.264248	0.382071	0.496776	0.095096
FE	6.030239	4.244453	7.679004	0.506723
HG	0.000059	0.000083	0.000012	0.000030
MG	1.122263	1.251406	1.093750	0.0
MN	0.010617	0.067395	0.056104	0.019392
MO	0.012164	0.019325	0.016112	0.028335
NA	0.650463	0.868812	0.473940	0.0
NI	0.082631	0.176412	0.161003	0.144036
P	1.697685	1.879967	2.459097	0.074529
PB	0.183524	1.655533	4.265661	2.154051
SB	0.023807	0.037933	0.020607	0.009202
SE	0.000969	0.000336	0.001335	0.002380
SI	0.023905	0.036842	0.0	0.026153
SN	0.046086	0.047442	0.042900	0.075125
SR	0.018557	0.023268	0.027840	0.000062
TI	0.057778	0.006376	0.127540	0.000739
TL	0.0	0.000461	0.0	0.001984
V	0.030664	0.037176	0.034037	0.001483
ZN	1.455935	2.780711	4.172058	0.639553
TOTAL	19.107010	19.280548	30.699188	3.938599

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TABLE 29

DATE: 8/31/79

TIME: 1415-1525

MODE: HTC

PERCENT HEAVY METALS IN PARTICULATE CATCHES

SASS RUN 7

ELEMENT	>10	10-3	3-1	0.1-1
	---------PARTICULATE SIZE FRACTION (MICRONS)------			
AG	0.000456	0.008454	0.006016	0.006726
AL	2.969911	2.802117	2.526788	0.0
AS	0.013476	0.022028	0.065820	0.038346
B	0.017939	0.021329	0.010023	0.0
BA	0.070241	0.021636	0.120929	0.003705
BE	0.000130	0.000150	0.0	0.000024
CA	5.208954	3.462006	5.402713	0.055566
CD	0.030979	0.059789	0.148060	0.061223
CO	0.023672	0.028721	0.026189	0.009680
CR	0.221303	0.244088	0.254630	0.308353
CU	0.279012	0.381967	0.564001	0.173873
FE	5.787746	4.629751	7.080338	1.385595
HG	0.000036	0.000089	0.000046	0.000044
MG	1.290301	1.283558	1.091628	0.047947
MN	0.055266	0.065601	0.060473	0.031062
MO	0.012516	0.018956	0.027500	0.046962
NA	0.715459	0.852158	0.707217	0.0
NI	0.024484	0.155882	0.159082	0.230723
P	1.602588	2.006936	2.097459	0.077420
PB	1.510421	2.077934	5.515097	2.452106
SB	0.025977	0.043649	0.035791	0.011411
SE	0.000188	0.000297	0.003176	0.002391
SI	0.018664	0.015249	0.0	0.015009
SN	0.011112	0.148128	0.033880	0.029957
SR	0.021908	0.022979	0.023874	0.000015
TI	0.030064	0.011590	0.056778	0.001288
TL	0.001883	0.000530	0.0	0.004428
V	0.036537	0.038120	0.033632	0.002327
ZN	1.762544	3.218270	4.454121	0.556214
TOTAL	21.743683	21.641861	30.505173	5.552392

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TABLE 30

DATE: 8/31/78

TIME: 1118-1218

MODE: HTC

DIST. OF ELEMENTS AMONG PARTICULATE SIZE FRACTIONS(%)

SASS RUN 6

ELEMENT	---------PARTICULATE SIZE FRACTION (MICRONS)------ >10	10-3	3-1	0.1-1
AG	45.50	36.37	0.32	17.80
AL	74.33	23.14	2.52	0.0
AS	49.88	30.64	8.97	10.51
B	75.20	24.63	0.0	0.17
BA	89.48	6.03	4.28	0.21
BE	71.16	27.18	0.0	1.66
CA	82.16	14.23	3.61	0.0
CD	54.94	29.13	7.40	8.53
CO	71.29	23.94	2.48	2.30
CR	83.78	6.42	3.63	6.18
CU	66.25	26.71	3.96	3.09
FE	80.15	15.73	3.24	0.87
HG	68.31	26.76	0.45	4.48
MG	74.52	23.17	2.31	0.0
MN	31.50	55.75	5.29	7.46
MO	55.96	24.79	2.36	16.89
NA	71.65	26.69	1.66	0.0
NI	53.10	31.61	3.29	12.00
P	73.50	22.70	3.38	0.42
PB	17.32	43.56	12.79	26.34
SB	65.71	29.19	1.81	3.29
SE	68.54	6.64	3.00	21.82
SI	63.63	27.34	0.0	9.02
SN	65.45	18.79	1.94	13.83
SR	71.55	25.01	3.41	0.03
TI	90.70	2.79	6.36	0.15
TL	0.0	33.33	0.0	66.67
V	72.49	24.50	2.56	0.45
ZN	59.51	31.69	5.42	3.39

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TABLE 31

DATE: 8/31/79

TIME: 1415-1525

MODE: HTC

DIST. OF ELEMENTS AMONG PARTICULATE SIZE FRACTIONS(%)

SASS RUN 7

ELEMENT	>10	10-3	3-1	0.1-1
	---------PARTICULATE SIZE FRACTION (MICRONS)------			
AG	9.69	58.60	3.82	27.88
AL	75.00	23.09	1.91	0.0
AS	44.75	23.87	6.54	24.84
B	71.19	27.62	1.19	0.0
BA	86.04	8.65	4.43	0.89
BE	70.72	26.70	0.0	2.59
CA	80.00	17.35	2.48	0.17
CD	46.34	29.17	6.63	17.86
CO	66.28	26.24	2.19	5.29
CR	60.02	21.60	2.07	16.31
CU	61.40	27.42	3.71	7.46
FE	74.39	19.41	2.72	3.47
HG	47.99	38.66	1.84	11.51
MG	73.69	23.91	1.87	0.53
MN	65.38	25.32	2.14	7.17
MO	43.63	21.56	2.87	31.94
NA	70.51	27.40	2.09	0.0
NI	19.57	40.65	3.80	35.98
P	68.63	28.04	2.69	0.65
PB	53.34	23.94	5.83	16.89
SB	59.70	32.73	2.46	5.12
SE	22.25	11.43	11.22	55.10
SI	70.25	18.73	0.0	11.02
SN	16.76	72.90	1.53	8.81
SR	72.73	24.89	2.37	0.01
TI	83.99	10.56	4.75	0.70
TL	64.50	5.92	0.0	29.58
V	72.45	24.66	2.00	0.90
ZN	57.71	34.38	4.36	3.55

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TABLE 32

HEAVY METALS BALANCES WITH SASS 6
COMBINING MONSANTO AND ISC ANALYSES

BASIS: ASH IN = ASH OUT + PARTICULATES
DATE: 8/31/78 TIME: 1118-1218 MODE: HTC

METAL	MG / KG DRY SOLIDS FED			% OF FEED ACCOUNTED FOR		% UNACCOUNTED FOR
	FEED	RESIDUE	PART.	RESIDUE	PART.	
AG	15.20	3.86	0.59	25.37	3.91	70.72
AS	0.41	1.99	4.07	490.28	******	*******
BE	2.25	0.78	0.02	34.45	1.02	64.53
CD	11.90	1.17	5.94	9.82	49.90	40.28
CR	554.00	367.73	30.30	66.38	5.47	28.15
CU	1061.00	844.13	59.02	79.56	5.56	14.88
FE	26149.96	21684.12	1113.21	82.92	4.26	12.82
HG	9.04	0.06	0.01	0.72	0.14	99.14
MN	178.00	143.35	4.99	80.53	2.80	16.66
NI	214.00	189.71	23.03	88.65	10.76	0.59
PB	975.00	251.64	156.87	25.81	16.09	58.10
SE	0.0	0.0	0.0	0.0	0.0	0.0
V	0.0	0.0	0.0	0.0	0.0	0.0
ZN	4587.99	3175.14	362.02	69.21	7.89	22.90

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TABLE 33

HEAVY METALS BALANCES WITH SASS 7
COMBINING MONSANTO AND ISC ANALYSES

BASIS: ASH IN = ASH OUT + PARTICULATES
DATE: 8/31/78 TIME: 1415-1525 MODE: HTC

METAL	MG / KG DRY SOLIDS FED			% OF FEED ACCOUNTED FOR		% UNACCOUNTED FOR
	FEED	RESIDUE	PART.	RESIDUE	PART.	
AG	15.20	3.94	0.42	25.91	2.78	71.30
AS	0.41	2.03	2.71	500.77	667.06	*******
BE	2.25	0.79	0.02	35.19	0.73	64.08
CD	11.90	1.19	6.01	10.03	50.53	39.44
CR	554.00	375.59	33.17	67.80	5.99	26.22
CU	1061.00	862.18	40.88	81.26	3.85	14.89
FE	26149.96	22147.80	700.05	84.70	2.68	12.63
HG	9.04	0.07	0.01	0.73	0.07	99.19
MN	178.00	146.42	7.61	82.26	4.27	13.47
NI	214.00	193.76	11.25	90.54	5.26	4.20
PB	975.00	257.02	254.71	26.36	26.12	47.51
SE	0.0	0.0	0.0	0.0	0.0	0.0
V	0.0	0.0	0.0	0.0	0.0	0.0
ZN	4587.99	3243.03	274.77	70.69	5.99	23.33

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TABLE 34

CAMPAIGN IV HEAVY METALS BALANCES WITH EPA-5 TEST 5
EMPLOYING ISC'S ANALYSES

BASIS: ASH IN = ASH OUT + PARTICULATES
DATE: 8/31/78 TIME: 1636-1736 MODE: HTC

METAL	MG / KG DRY SOLIDS FED			% OF FEED ACCOUNTED FOR		% UNACCOUNTED FOR
	FEED	RESIDUE	PART.	RESIDUE	PART.	
AG	15.65	4.52	0.74	28.90	4.74	66.35
AS	0.27	2.33	4.10	879.42	******	*******
BE	2.09	0.91	0.02	43.51	1.16	55.33
CD	11.86	1.37	4.76	11.56	40.16	48.28
CR	569.00	431.33	31.48	75.81	5.53	18.66
CU	1109.50	990.14	54.89	89.24	4.95	5.81
FE	26718.49	25434.80	1177.50	95.20	4.41	0.40
HG	37.99	0.08	0.03	0.20	0.09	99.71
MN	181.50	168.15	9.19	92.64	5.07	2.29
NI	230.50	222.52	11.87	96.54	5.15	-1.69
PB	1007.00	295.17	379.00	29.31	37.64	33.05
SE	0.0	0.0	0.01	0.0	0.0	0.0
V	0.0	90.93	2.85	0.0	0.0	0.0
ZN	4713.99	3724.34	462.72	79.01	9.82	11.18

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Se and V are not detectable in the feed.

Most metals were primarily retained by the residue char. One exception is Cd, with 40-50% of Cd in the feed leaving with particulates. The large amount of Cd and Pb which are not accounted for could also be leaving as a volatile substance via the furnace exhaust.

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Measurements of Other Substances During HTC Mode

NO_x - 0.06 mg/kg of NO_2 was at the afterburner exit.

SO_x - 1.6 gm/nm^3 (9.9 X 10^{-5} lb/scf) of SO_2 was at the afterburner exit.

Hydrocarbons - the data show 2.2% hydrocarbons as CH_4 at the inlet to the afterburner and 0.24% hydrocarbons at the afterburner outlet.

The O_2/combustibles meter registered about 3% O_2 and 4% combustibles on the top three hearths. That is, there was a reducing atmosphere. The bottom three hearths, however, had an oxidizing atmosphere with 10% O_2 and no combustibles. 1 to 4% combustibles on hearth 1 is consistent with the 2.2% before the afterburner cited above.

ANALYTICAL TECHNIQUES USED FOR METALS DETERMINATIONS

The feed and product samples were analyzed for a list of 16 heavy metals by atomic absorption spectroscopy (AA). The sludge was from an industrial area and had easily detectable concentrations of most heavy metals of interest except for Be, Cr^{+6}, Se and V. The sludge was spiked only with ferric chloride and calcium hydroxide flocculents in the treatment process.

Particulates were collected to determine loading, size distribution and metals content within each size distribution. Particulates were collected in two separate pieces of equipment (EPA-5 and SASS) and the catches from both devices were analyzed.

The SASS catches were of chief importance and were analyzed for 25 elements by Inductively Coupled Argon Plasma spectroscopy (ICAP) and 4 elements by AA. As a cross-check the EPA-5 catch was also analyzed for 15 of these elements by AA.

Upon further analytical evaluation, additional checks for the ICAP analyses were made for four of the SASS samples. The results for one sample are summarized in Table 35. The sources of the analyses are explained in the accompanying notes.

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In general, the analyses are within 20% of each other with

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specific exceptions. ICAP measured twice as much Cd as the other methods. Hg differs in the two AA tests. ICAP measured twice as much P as X-ray fluorescence (XRF). XRF measured many times the Si, Sn, and Ti that ICAP did. V was 30-60% lower by the AA methods. The ICAP/HNO_3 technique (ICAP analysis of HNO_3-digested sample) shows generally higher concentrations than AA/HNO_3 (AA analysis of HNO_3-digested sample). ICAP analysis when adjusted for concentrations in insoluble residue showed slightly higher concentrations, but still less than AA/HF. Although the ICAP/HNO_3-insoluble residue has only a small additional amount of metal for the sample in Table 35, there are numerous samples in which the residue contains more of specific metals than the HNO_3-soluble part. So for the calculation of heavy metals balances ICAP plus RESIDUE was preferred over ICAP/HNO_3.

It can be gathered from the preceding that caution is required in interpreting metals analyses. To obtain the standard deviation of heavy metals determinations it would be necessary to run numerous analyses on identical samples. This was beyond the scope of this work. In evaluating the accountability of metals in this work, the range of 100% $\pm$ 30% metal out/metal fed was considered to be the best accuracy obtainable from the data available.

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TABLE 35. COMPARISON OF ANALYTICAL METHODS

CONCENTRATIONS IN mg/kg:SASS RUN 2 GREATER THAN 10 um CATCH

NOTE:	1	2	3	4	5
Analysis:	XRF	AA/HF	AA/HNO_3	ICAP/HNO_3	ICAP + RESIDUE
METAL					
Al	21,000	-	-	23,622	-
Ba	1,000	-	-	830	
Be	-	2	2	1.42	1.42
Ca	58,000	-	-	42,492	-
Cd	200	189	175	461	463
Co	200	-	-	241	-
Cr	2,600	2100	2100	1,890	1921
Cu	3,200	2390	2120	2,310	2335
Fe	77,000	70000	50000	48,751	49556
Hg	-	2.3	0.7	-	-
Mg	7,300	-	-	10,408	-
Mn	300	540	450	455	463
Na	7,200	-	-	6,727	-
Ni	800	700	500	661	667
P	8,500	-	-	15,598	-
Pb	9,900	7300	6000	6,983	7095
Sb	200	-	-	252	-
Si	90,000	-	-	788	-
Sn	1,600	-	-	309	-
Ti	5,700	-	-	403	-
V	300	200	100	328	328
Zn	17,000	12000	11000	11,757	11868

NOTES:

1. X-ray Fluorescence.
2. Atomic absorption analysis of HF digested sample.
3. Atomic absorption analysis of HNO_3 digested sample.
4. Inductively coupled argon plasma analysis of HNO_3 digested sample.
5. Total of preceding column plus additional amounts derived from AA/HF analysis of HNO_3 insoluble residue.

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SECTION 6

DISCUSSION OF EXPERIMENTAL RESULTS

GENERAL

In this section, the three modes of furnace operation are compared and contrasted. The mass and energy balances are discussed first. Next, each of the substances of interest in this study is considered separately.

MASS AND ENERGY BALANCES

The mass and energy balances serve as a check of the accuracy of pollutant concentration levels measured after the afterburner. They show that there was probably a leakage of tramp air into the afterburner exhaust duct (see below). They also indicate that the particulate emission levels measured with the EPA-5 and SASS equipment are higher than the actual values by 16% to 30% during the sludge combustion tests.

Tables 7, 16, 17, 26, 27, 36, and 37 summarize the mass and energy balances for each mode of operation. The afterburner exhaust gas compositions given there are calculated from the material fed to the system rather than from measurements in the exhaust duct.

There are four checks of the degree of accuracy of the mass balance. The first comprises the energy balances. The blank mode is used to determine cooling losses in the MHF and afterburner; so the energy balance closes exactly for the BLANK mode when 89,000 BTU/hr. are lost from the afterburner and 2.078 x 10^8 joules/hr (197,200 BTU/hr.) are lost from the furnace. These quantities determine the constants in empirical heat loss equations as follows:

For afterburner:

$$R_{AB} = 110{,}000(T_{AB} - 15^{\circ}C)$$

For furnace:

$$R_F = 42{,}500(1.5\Delta T_1 + \Delta T_2 + \Delta T_3 + \Delta T_4 + \Delta T_5 + 1.5\Delta T_6)$$

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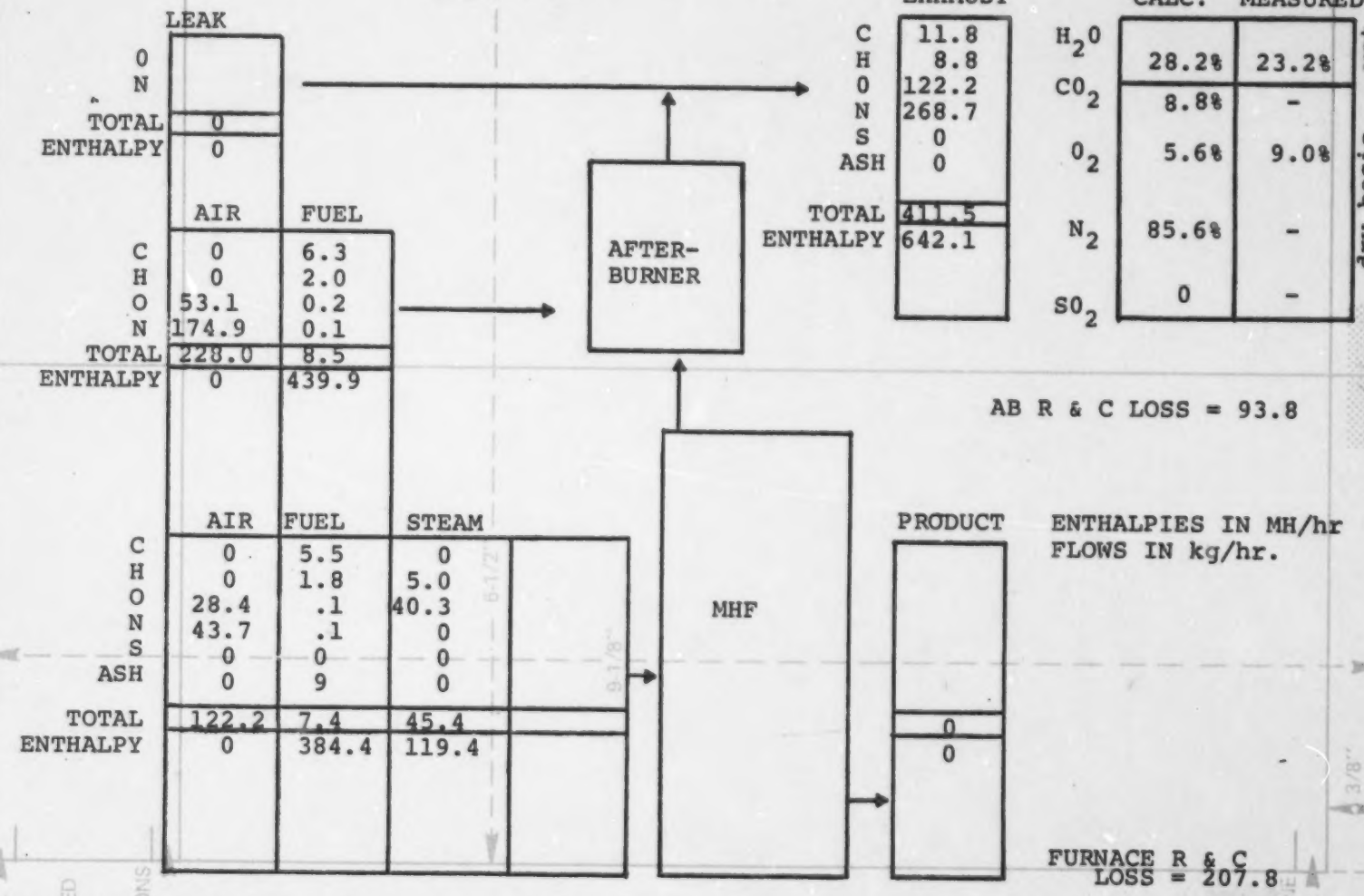
TABLE 36

MASS & ENERGY BALANCES

BLANK MODE



TOTAL IN 411.5 kg/hr 943.7 MJ/hr TOTAL OUT 411.5 kg/hr 943.7 MJ/hr

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TABLE 37

MASS & ENERGY BALANCES

BLANK MODE

	LEAK
O	21.3
N	70.1
TOTAL	91.4
ENTHALPY	0

	AIR	FUEL
C	0	6.3
H	0	2.0
O	53.1	0.2
N	174.9	0.1
TOTAL	228.0	8.5
ENTHALPY	0	439.9

	AIR	FUEL	STEAM
C	0	5.5	0
H	0	1.8	5.0
O	28.4	0.1	40.3
N	93.7	0.1	0
S	0	0	0
ASH	0	9	0
TOTAL	122.2	7.4	45.4
ENTHALPY	0	384.4	119.4

AFTER-BURNER

MHF

	EXHAUST
C	11.8
H	8.8
O	143.5
N	338.8
S	0
ASH	0
TOTAL	502.9
ENTHALPY	642.1

GAS ANALYSES	CALC.	MEASURED
H_2O	23.5%	23.2%
CO_2	6.8%	-
O_2	9.0%	9.0%
N_2	84.2%	-
SO_2	0	-

wet

dry basis

AB R & C LOSS = 93.8

PRODUCT

0
0

ENTHALPIES IN MJ/hr
FLOWS IN kg/hr.

FURNACE R & C LOSS = 207.8

TOTAL IN 502.9 kg/hr 944 MJ/hr TOTAL OUT 502.9 kg/hr 944 MJ/hr

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1. Units in joules/hr.
2. Temperature units in C.
3 $\Delta T_1 - \Delta T_6$ are difference between hearth temperatures and surroundings.

For the INC, LTC, and HTC modes the heat balances can then be determined. They agree as follows.

TABLE 38. ENERGY OUT/ENERGY IN

MODE	$\frac{\text{JOULES OUT}}{\text{JOULES IN}}$ X100%
INC	113.3%
LTC	95.7%
HTC	93.4%

The second check of the mass balance is % O_2 measured at sample point 6 downstream from the afterburner. Each mode of operation compares as follows.

TABLE 39. DRY VOLUMETRIC % O_2

MODE	CALCULATED	MEASURED
BLANK	5.6	9.0
INC	11.1	9.5
LTC	3.2	9.5
HTC	2.7	9.0

The disagreement here could be the result of a leak of air into the system for BLANK, LTC, and HTC modes of operation.

A third check of the mass balances is the percent moisture measured at sample point 6. The comparison is as follows.

TABLE 40. VOLUMETRIC % H_2O

MODE	CALCULATED	MEASURED
BLANK	28.2	23.2
INC	18.0	22.6
LTC	27.6	21.8
HTC	26.9	22.3

Again, the disagreement for BLANK, LTC, and HTC could be the result of an in-leakage of air to the system.

The explanation of such a leak is that the ID fans pull a constant volume of exhaust gases regardless of the gas output by the system. If the gas output is low, there is an in-leakage of air. If as in the INC mode, the output is high, there is no

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in-leakage of air.

As a result of this reasoning, it is assumed that there is an air leak for the BLANK, LTC, and HTC Modes in Tables 17, 27 and 37. If the leak is determined from the measured O_2 levels at sample point 6 the calculated H_2O levels are diluted.

TABLE 41. VOLUMETRIC % H_2O

MODE	CALCULATED	MEASURED
BLANK	23.5	23.2
LTC	17.3	21.8
HTC	19.4	22.3

This fits well for the BLANK mode. For LTC and HTC this is too much dilution to give agreement on % H_2O; so there are other factors involved there.

The fourth check of the mass balances is the gas flow rate derived from pitot tube measurements taken at sample point 6. The comparisons are below.

TABLE 42. TOTAL GAS FLOW RATE (Sample Point 6)

MODE	CALCULATED NO LEAK	CALCULATED LEAK	MEASURED
BLANK	907.1	1108.7	1904.1
INC	1711.5	-	1991.5
LTC	1075.8	1532.8	1988.9
HTC	1061.8	1496.5	1865.4

Even with the estimated air leakage, the measured gas flow rates are higher by 72% for BLANK, 30% for LTC and 25% for HTC. The INC mode measures 16% higher than calculated.

There must be an additional error somewhere in the data to account for this discrepancy. The pitot readings are a likely source of this error. The duct is so small (8" I.D.) compared with the size of the sampling probe that the presence of the probe may actually effect the gas velocity. Merely as an obstruction, the probe could be responsible for 8% higher velocity readings by reducing the cross-sectional area.

Another possible source of error is that afterburner exhuast temperatures were measured with an unshielded thermocouple. ASTM procedure[2] recommends a shielded thermocouple for stack gas temperatures above 370 C (700 F) compared with over 690 C (1100F) at sample point 6. This would result in a 9% higher stack mass rate erroneously taken if the temperature were really 760 C (1400 F)

(2) ASTM, 1974, p. 588, Designation: D-298-71.

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Since the particulate emissions rate in lb/hr. is determined from the measured flow rate at Point #6, it is only as reliable as the pitot measurement. It can only be said that the measured emissions serve as upper limits to the actual values. They could be high by as much a factor of two.

RESULTS OF PARTICULATE SAMPLING

Table 8 lists the particulate levels exiting the afterburner for eleven valid tests. Background loadings measured during the BLANK Mode of operation show that there is at most an 8% error in the particulate loadings of the INC, LTC, and HTC Modes, resulting from contamination.

Two invalid EPA-5 tests were discarded from consideration. Test #3 was not isokinetic. Test #6 was performed after the HTC run was over.

The incineration mode had the highest particulate emissions average rate of 1.5 kg/hr. (112 gm/kg dry solids fed). The LTC mode had the lowest rate of 0.9 kg/hr. (58 gm/kg dry solids fed). The HTC mode emissions rate was 1.1 kg/hr. (72 gm/kg dry solids fed). This variation is consistent with the variation in maximum drophole velocity, implying that entrainment is the main source of particulates. The velocity during the INC Mode is on the order of 3m/sec; velocity for the LTC Mode is about 1.2 m/sec; velocity for the HTC Mode is about 1.5 m/sec.

None of the log-normal plots of particulate size distributions in Figures 6, 9, or 11 are linear (except for the BLANK mode). The deviations are due to the scarcity of particulates in the 1-3 μ size fraction.

BEHAVIOR OF HEAVY METALS IN THE MULTIPLE HEARTH FURNACE

In this section, the behavior of individual heavy metals is summarized. It is difficult to conclude anything about an individual metal if it has not been completely accounted for by the outlet streams of the furnace system, so this aspect is considered first. Next, mention is made about the fraction of each metal retained in the furnace product.

Silver

Silver is summarized by the chart in Figure 12 . In this chart, each bar represents Ag data from Tables 13-15, 22-24, and 32-34, respectively. The Ag accountability is best for the INC mode. The quanitity of Ag in particulates is small compared with the quantity of Ag in the product. Of the silver accounted for across the system, approximately 2 to 10% appears in the particulate (20 to 60% in the product). It appears Ag in an

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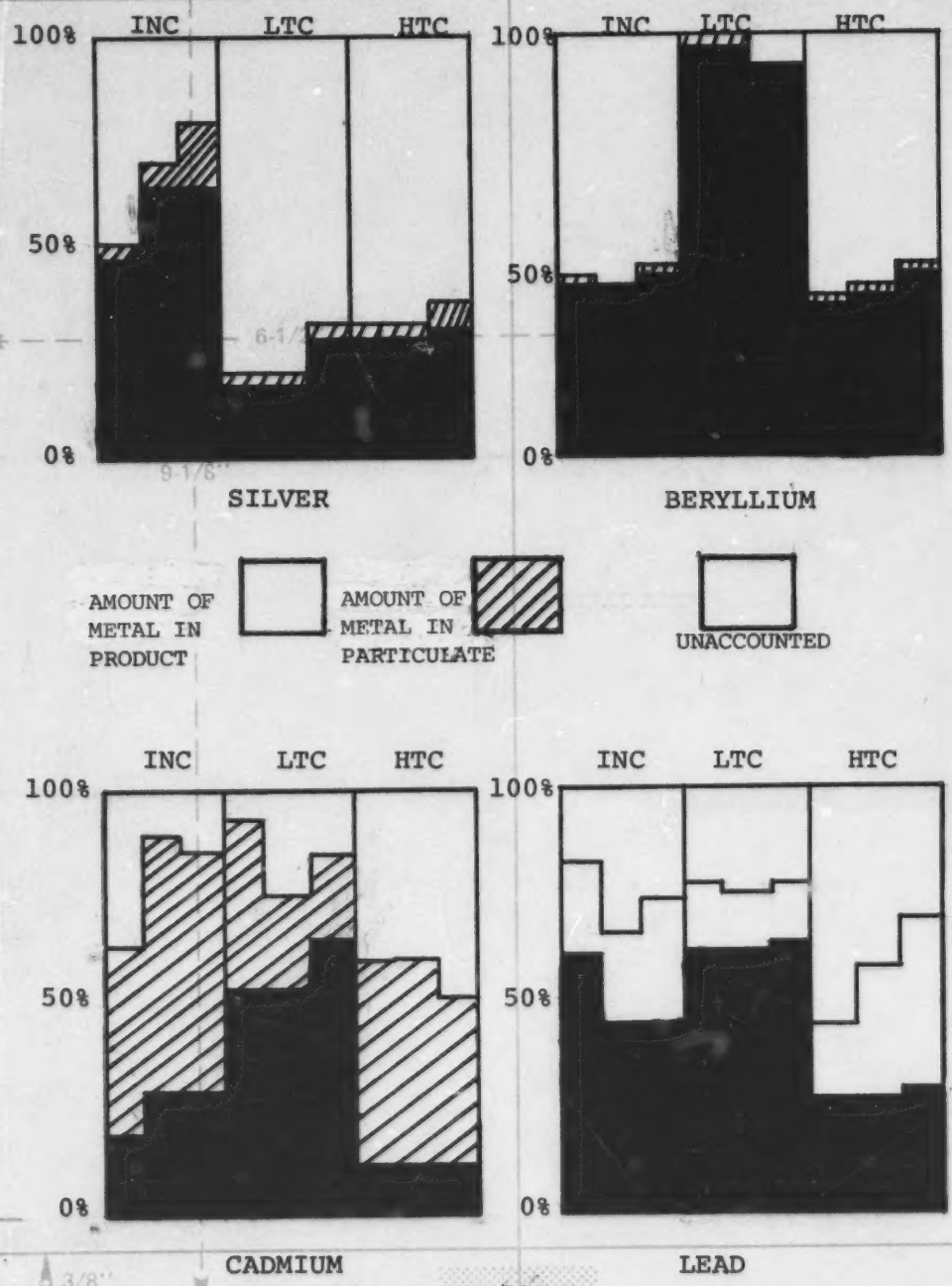
FIGURE 12

ACCOUNTING OF METALS IN FURNACE FEED; SUMMARY



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oxidizing atmosphere is not a very volatile metal.

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Arsenic

The arsenic measurements are inconsistent in that the arsenic content of the furnace feed is accounted for many times over by the arsenic content in the outlet streams for every mode of operation. Arsenic concentrations are higher in the particulate than in the product.

Beryllium

Beryllium is also depicted in Figure 12. Accountability is best for the LTC mode. Beryllium is mostly unaccounted in the INC and HTC modes. Only 1-3% of Be in the feed exits the system vis the particulates. The data show that Be was retained in the furnace residue during the LTC mode of operation.

Cadmium

6-1/2"

The summary chart for cadium is in Figure 12. Cd is approximately 60% retained in the LTC mode char. It is about 30% retained in the INC mode residue. It is not well accounted for in the HTC mode. These retentions are consistent with earlier work that showed a relationship between Cd retention and furnace temperature.[3] It is indicated that Cd, although a very volatile metal, could be controlled more closely by a lower temperature operation than used in the LTC mode covered by this report.

Lead

There is also a summary chart for lead in Figure 12. 50-60% of the feed lead was retained in the residue from INC and LTC modes. 30% of the feed lead was retained by the HTC product. Again, a lower temperature level LTC mode might help hold the lead in the solid product.

Chromium, Copper, Iron, Manganese, and Nickel

These metals behave similarly and can be discussed together. 70-130% of total quantity in the MHF feed for each of the metals is detected in the product for INC, LTC, and HTC. 2-11% of the amounts in the feed are detected in particulates at sample point 6. These metals are retained by the product regardless of the mode of operation.

Mercury

Mercury in the feed is almost entirely unaccounted for by the furnace product or particulate streams.

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Selenium and Vanadium

Selenium and Vanadium concentrations were below detectable limits in the feed material. They were detectable in the product and particulates.

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Zinc

The accountability of Zn is 75-105%. Most of the feed Zn is found in the product. 3-4% of feed Zn appears in the particulates in the LTC mode. 5-10% of feed Zn appears in the particulates in the INC mode. 6-10% of feed Zn appears in the particulates in the HTC mode.

DISCUSSION OF SULFUR DATA

From the ultimate analysis given in Tables 3 and 5, the sulfur analyses show the feeds containing, on an average, 0.04 kgS per kg ash (equiv. 0.08 kgs SO_2 per kg. ash). The average sulfur content of the solid residue was 0.02 kgs. S per kg ash. (Equivalent 0.04 kgs. SO_2 per kg. ash). These results indicate that 50% of the feed sulfur stays in the solid residue under all modes of operation.

Table 43 shows the predicted SO_2 evolved (lbs. per hr.) using selective analysis from Tables 3, 5, and 25. Because of inconsistencies in the MRC data presented in Table 25 and not knowing the particular time of sampling, only certain analyses from Tables 3 and 5 were used to try to coincide with MRC SO_2 concentrations. The predicted data assumes ash-in equals ash-out and all sulfur not appearing in the residue is evolved in the gas as SO_2.

DISCUSSION OF FEED AND PRODUCT CHLORIDE ANALYSES

On the basis of ash-in equals ash-out, the chloride analyses given in Tables 4 and 6 show 0.009 kg Cl per kg ash in the feed. In the residue, for incineration there is 0.003 kgs. Cl per kg ash and for low temperature char (LTC) there is 0.005 kgs Cl per kg ash. It is assumed what chlorides do not stay in the solid products, they are evolved with the exhaust gas. The evolved chlorides calculate to be:

0.09 kg per hr. Cl evolved for incineration;
0.06 kg per hr. Cl evolved for LTC.

FURNACE DATA CONCERNING OTHER TOXIC MATERIALS

Feed and product samples were tested for pesticides and PCB's. Also, one scrubber sample taken during the INC mode was tested for pesticides and PCB's. During this mode of operation, 2.1 mg/kg of chlorodane and 0.08 mg/kg of dieldrin were

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present in the feed, and no pesticides were detected in the residue or scrubber effluent water. No measurable PCB's were present in any residue samples.

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NO_x concentrations are less than 0.07 mg/kg in all modes of operation.

TABLE 43. SULFUR DIOXIDE EMISSIONS

MODE	gm SO_2/kg dry solids fed PREDICTED	MRC	MRC SAMPLE #
INC	21	23	1
LTC	13	11	4
HTC	16	16	5

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APPENDIX A

Included below are the results of lab analyses done on all samples except the SASS particulates and gas samples. The first part of the sample number refers to the sampling location indicated in Figure 2 of the text.

Notes:

1. Heavy metals analyses were performed by ISC labs by atomic absorption spectrographic analysis of HF-digested samples. Metals used were Perkin-Elmer procedure AY3[A-1] and method 301A-VII[A-2].

2. Analyses for chloradane, dieldrin and PCP's were also done by ISC labs.

3. The proximate analyses were done by Nichols Engineering according to the following procedure: A porcelain crucible is dried to constant weight, tarred and filled part way with sample. With a lid on the crucible, it is devolatilized at 950 C for 7½ minutes in a muffle furnace. It is cooled and weighed. It is ashed with lid off for 2 hours at 950 C in the muffle furnace. It is again cooled and weighed.

4. Ultimate analyses were done by Princeton Testing Labs according to method in Reference A-3.

5. Heating values were done by Nichols Engineering personnel. Heating value is measured in a calorimeter inside of which is a Parr* peroxide bomb[A-4] where the sample is combusted. See reference.

* Trade name; use of trade name does not indicate USEPA endorsement.

A-1 Analytical Methods for AA Spectrography, Perkin-Elmer Corp. Norwalk, CT., 1964.

A-2 Standard Methods for Evaluation of Waste Water, American Public Health Assc., Washington D.C., 1975.

A-3 Standard Methods of Chemical Analysis, 6th Edition, Vol.2A, Princeton, N.J., 1963.

A-4 Parr Instrument Co., Moline, IL., 1957.

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TABLE A-1

LABORATORY ANALYSES
SLUDGE TO FILTER PRESS
CONCENTRATIONS IN mg/LITER
(Except where noted)

SAMPLE #	1 - 3	1 - 5	1 - 12	1 - 16	
Date	8/21	8/21	8/23	8/24	
Ag	15.7	17.3	5.4	<5.7	
As	24	22.3	3.4	0.44	
Be	<2.2	<2.2	<5.4	<5.7	
Cd	17.2	19.9	<5.4	<5.7	
Cr^{+3}	568	493	116	31	
Cr^{+6}	<2.2	<2.2	<5.4	<5.7	
Cr (Total)	568	493	116	31	
Cu	1446	1072	212	71	
Fe	31,023	28,717	12,321	14,050	(1)
Hg	8.84	10.57	2.53	1.49	
Mn	218	206	400	463	
Ni	219	217	53.7	56.5	
Pb	876	737	215	56.5	
Se	1.54	.852	2.14	1.11	
V	<220	<220	<540	<570	
Zn	3774	3493	939	269	
Chlorodane ug/L	436	0	150	-	
Dieldrin ug/L	5.57	0	2.69	-	(2)
PCB "	0	0	0	0	
% SOLIDS	7.71	9.10	1.48	1.15	(3)
AVG. BOD (5-Day)	----	3065	3824	3134	

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TABLE A-2

ISC HEAVY METALS ANALYSES
(CONCENTRATIONS IN mg/kg)
(Except Where Noted)

SAMPLE #	2 - 1	2 - 2	2 - 3	2 - 4	2 - 5	
Date	8/30	8/30	8/29	8/30	8/29	
Time	17-2400	17-2400	19-2000	6-1200	8-1300	
Mode of Operation	LTC	LTC	INC	LTC	INC	
Ag	14.5	13.9	19.2	13.6	15.8	
As	0.084	0.091	0.175	0.621	0.507	
Be	0.94	0.99	<0.96	<0.97	1.98	
Cd	10.76	9.90	11.54	9.69	16.81	
Cr^{+3}	560	545	519	523	479	
Cr^{+6}	<0.94	<0.99	<1.90	<1.90	<2.00	
Cr (Total)	560	545	519	523	479	
Cu	1115	1114	1135	1143	1053	(1)
Fe	27,624	27,720	27,885	29,064	21,748	
Hg	17.9	16.4	15.7	23.0	20.8	
Mn	185	188	173	233	180	
Ni	225	238	250	213	217	
Pb	1030	1020	962	969	939	
Se	< 0.023	< 0.026	< 0.025	< 0.027	< 0.024	
V	<9.4	<9.9	<19.2	<19.0	<19.8	
Zn	4682	4505	4615	4553	4251	
Chlorodane ug/L	1.15	1.69	1.75	1.07	1.16	
Dieldrin ug/L	.078	.099	.090	.042	.039	(2)
PCB'S "	0	0	0	0	0	
% Solids	52.6	52.6	48.1	52.9	46.2	
% Vols.	52.1	51.5	51.2	52.9	51.0	(3)
% Ash	38.2	39.1	40.10	37.9	39.3	
% F.C.	9.7	9.4	8.8	9.2	9.7	
% C	38.35	35.95	33.78	37.88	34.55	
%H	5.13	5.26	4.76	5.35	4.69	(4)
%N	1.19	1.67	1.96	1.96	1.96	
% Ash	40.13	39.02	41.64	41.18	40.76	
% S	1.66	1.44	1.69	1.38	1.27	
% Cl	.35	.40	-	-	-	
HV(BTU/#Solids)						
measured	8041	11,494	8218	7723	8029	(5)
Calculated	8022	7644	7051	8139	7093	

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TABLE A-2
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ISC HEAVY METALS ANALYSES
FURNACE FEED
(CONCENTRATIONS IN mg/kg)
(Except where noted)

SAMPLE #	2 - 6	2 - 7	2 - 8	2 - 9	2 - 10	
Date	8/31	8/29	8/29	8/30	8/31	
Time	1700	18-2400	18-2400	12-1900	11-1730	
Mode of Operation	HTC	INC	INC	LTC	HTC	
Ag	16.1	17.6	16.5	14.7	15.2	
As	0.125	0.471	0.582	1.264	0.406	
Be	1.93	1.85	1.94	0.98	2.25	
Cd	11.82	15.75	11.64	9.80	11.90	
Cr^{+3}	584	565	534	539	554	
Cr^{+6}	< 0.94	< 0.93	< 0.97	< 0.98	< 0.94	
Cr (Total)	584	565	534	539	554	(1)
Cu	1158	1153	1081	1024	1061	
Fe	27,287	28,717	29,092	23,836	26,150	
Hg	67.0	34.5	20.2	15.3	9.04	
Mn	185	195	204	230	178	
Ni	247	259	242	225	214	
Pb	1039	1019	1018	931	975	
Se	< 0.024	< 0.027	< 0.024	< 0.024	< 0.028	
V	< 9.4	< 9.3	< 9.7	< 9.8	< 9.4	
Zn	4840	4493	4461	4166	4588	
Chlorodane ug/L	1.23	3.09	2.22	1.86	1.02	
Dieldrin ug/L	0	.110	.065	.088	.033	(2)
PCB'S "	0	0	0	0	0	
% Solids	51.6	50.3	50.3	49.8	55.2	
% Vols.	49.3	53.4	48.8	-	51.8	(3)
% Ash	46.3	38.2	47.7	-	38.2	
% F.C.	4.4	8.4	3.5	-	10.0	
% C	37.46	36.76	35.50	36.09	36.71	
% H	5.50	4.94	5.03	5.10	5.54	
% N	1.89	1.94	1.70	1.77	2.05	
% Ash	41.38	43.23	41.76	41.21	39.07	(4)
% S	1.49	1.52	1.77	1.54	1.32	
% Cl	-	-	.36	-	-	
HV (BTU/# Solids)						
Measured	8650	7536	8709	8475	9128	
Calculated	8171	7756	7532	7656	7974	(5)

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TABLE A-3
LABORATORY ANALYSES
PRESS FILTRATE
(CONCENTRATIONS IN mg/l - Except where noted)

SAMPLE NO.	3 - 3	3 - 8	3 - 9	3 - 17	3 - 18	3 - 23
Date	8/21	8/22	8/22	8/23	8/23	8/24
Ag	0.02	0.03	0.03	0.02	0.02	0.01
As	0.008	0.0015	0.0157	0.0021	0.0015	0.0007
Be	0	0	0	0	0	0
Cd	0.01	0.02	0.02	0.02	0.03	0.02
Cr^{+3}	0.20	0.03	0.21	0.13	0.08	0.10
Cr^{+6}	----------all less than 0.01 ppm----------					
Cr (Total)	0.20	0.03	0.21	0.13	0.08	0.10
Cu	0.32	0.10	0.33	0.28	0.13	0.12
Fe	210	4.5	82	102.5	114	110.5
Hg	0.0028	0.0017	0.0031	0.0032	0.0014	0.0018
Mn	4.30	0.15	2.60	3.60	3.90	3.80
Ni	0.1	0.2	0.2	0.2	0.2	0.2
Pb	0.4	0.2	0.3	0.3	0.2	0.2
Se	----------all less than 0.001 ppm----------					
V	0	0	0	0	0	0
Zn	1.32	0.13	1.60	1.08	0.42	0.43
Chlorodane ug/L	0	0	-	0	-	-
Dieldrin ug/L	0	.31	-	0	-	-
PCB "	0	0	-	0	-	-
Solids pH	5.6	6.65	5.6	5.3	6.75	-
Avg. BOD (5 day)	3639	3725	3622	3226	3244	3395

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TABLE A-4

ISC HEAVY METALS ANALYSES
FURNACE PRODUCT
(CONCENTRATIONS IN mg/kg)
(Except where noted)

SAMPLE #	4 - 1	4 - 2	4 - 3	4 - 4	4 - 5	
Date	8/30	8/29	8/31	8/30	8/29	
Time	19-20 2300	15-17 21-2300	12-13 15-1700	14-1700	11-1400	
Mode of Operation	LTC	INC	HTC	LTC	INC	
Ag	6.90	27.1	9.90	4.90	19.4	
As	4.58	10.76	5.11	3.06	8.85	
Be	1.98	1.94	1.99	1.95	1.94	
Cd	12.85	10.15	3.00	10.70	8.70	
Cr^{+3}	758	962	944	794	1262	
Cr^{+6}	< 0.99	< 0.99	< 0.99	< 0.98	< 0.97	
Cr (Total)	758	962	944	794	1262	(1)
Cu	1420	2210	2167	1569	2373	
Fe	53,364	63,908	55,666	54,613	66,007	
Hg	.239	.249	.166	.224	.500	
Mn	380	475	368	375	471	
Ni	415	567	487	517	544	
Pb	1300	1269	646	1121	1359	
Se	< 0.097	< 0.093	< 0.098	< 0.096	< 0.095	
V	98.9	194	199	98	194	
Zn	6820	8329	8151	7213	10,289	
Chlorodane ug/L	0	0	0	0	0	
Dieldrin ug/L	0	0	0	0	0	(2)
PCB'S	0	0	0	0	0	
% Vols.	5.0	4.2	2.8	5.2	5.8	
% Ash	81.9	95.0	88.3	81.3	91.2	(3)
% F.C.	13.1	0.8	8.9	13.5	3.0	
% C	15.27	4.23	7.90	15.34	5.85	
% H	0.62	0.20	0.13	0.37	0.25	
% N	5.74*	0.92*	1.49	0.049	0.014	(4)
% Ash	82.05	95.72	90.41	83.02	91.48	
% S	1.95	1.79	1.69	2.18	1.82	
% Cl	0.43	0.27	-	-	1.82	
HV (BTU/#						
Measured	3860	-	2446	3199	No Ignition	(5)
Calculated	2529	718	1193	2388	955	

*Probably X100 Too High

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TABLE A-4
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LABORATORY ANALYSES OF
FURNACE PRODUCT
(Concentrations in mg/kg - Except where Noted)

SAMPLE #	4 - 6	4 - 7	4 - 8	
DATE	8/30	8/30	8/29	
TIME	19-20 2300	6,9-1200	15-17,21-2300	
MODE OF OPERATION	LTC	LTC	INC	(1)
Ag	8.8	8.1	24.4	
As	3.93	5.22	19.23	
Be	1.97	2.01	1.95	
Cd	14.70	14.60	8.8	
Cr^{+3}	825	822	906	
Cr^{+6}	<0.98	<1.00	<0.98	
Cr (Total)	825	822	906	(2)
Cu	1793	1793	2116	
Fe	55,026	54,304	64,344	
Hg	0.201	0.441	0.252	
Mn	349	398	477	
Ni	413	398	541	
Pb	1385	1504	990	
Se	<0.096	<0.099	<0.096	
V	98	201	195	
Zn	7664	7643	8581	
Chlorodane ug/L	0	0	0	
Dieldrin ug/L	0	0	0	
PCB's "	0	0	0	
% Vols.	5.8	5.7	3.3	
% Ash	80.5	84.9	95.1	(3)
% F.C.	13.7	9.4	1.6	
% C	15.26	13.27	4.93	
% H	0.34	0.45	0.24	
% N	0.056	0.035	0.007	(4)
% Ash	82.07	82.72	91.18	
% S	1.91	1.92	1.60	
% Cl	-	-	-	
HV (BTU/#)				
Measured	2921	-	-	(5)
Calculated	2344	2084	763	

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TABLE A-6

ISC HEAVY METALS ANALYSES
EPA-5 FILTER CATCHES
(Concentrations in mg/kg)

SAMPLE #	6-1	6-2	6-4	6-5	
DATE	8/28	8/29	8/30	8/31	
TIME	2130	1500	0000	1600	
Ag	< 645	424	194	144	
As	32.3	158	604	633	
Be	< 323	< 28	< 9.7	< 5.7	
Cd	< 323	1047	755	563	
Cr +3	484	909	1399	583	
Cr +6	< 323	< 24.9	< 9.7	< 5.7	
Total Cr	484	909	1399	583	
Cu	968	4688	6757	7451	(1)
Fe	< 323	35,411	66,989	28,243	
Hg	-	-	-	-	
Mn	< 323	200	368	178	
Ni	< 3226	249	581	459	
Pb	< 3226	68,329	19,555	121,929	
Se	< 32.2	12.25	0.95	1.69	
V	< 3226	< 249	194	172	
Zn	< 323	< 323	6050	65,299	
Filter Catch (mg)	3.1	40.1	103.3	174.2	

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ISC HEAVY METALS ANALYSES
EPA-5 CYCLONE AND WASH
(Concentrations in mg/kg)

SAMPLE	6-12	6 - 14	6 - 15	6 - 17	
DATE	8/29	8/30	8/31	8/31	
TIME	1500	0000	1630	2030	
Ag	17	31	29	35	
As	169	105.5	231	180	
Be	< .76	< .67	< 1.54	2.22	
Cd	210	137	270	231	
Cr^{+3}	1355	2266	1426	2109	
Cr^{+6}	< 0.76	< 0.67	< 1.54	< 0.74	(1)
Total Cr	1355	2266	1426	2109	
Cu	1947	2350	2428	2868	
Fe	57,256	63,784	61,671	74,014	
Hg	-	-	-	3.066	
Mn	477	520	501	574	
Ni	504	839	648	711	
Pb	4008	3525	12,720	12,582	
Se	0.15	0.134	0.151	0.218	
V	137	134	154	163	
Zn	17	31	29	35	
Wt. Particulates (mg.)	1309.8	1489.3	648.5	1337.6	

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TABLE A-7
LABORATORY ANALYSES
SCRUBBER EFFLUENT
(Concentrations in mg/l - except where noted)

SAMPLE #	7 - 1	7 - 2	7-3	7 - 4
DATE	8/30	8/29	8/31	8/30
TIME				
Ag	0	0.02	0.09	0
As	0.0016	0.052	0.10	0.035
Be	0.1	4.0	15.5	1.1
Cd	0.01	0.12	0.44	0.04
Cr^{+3}	0.21	2.40	10.50	0.70
Cr^{+6}	----------less than 0.01 ppm----------			
Total Cr	0.21	2.40	10.50	0.70
Cu	0.20	2.45	10.50	0.70
Fe	5.5	143.5	297	98.5
Hg	0.0022	0.0506	0.1103	0.0506
Mn	0.13	0.55	2.10	0.24
Ni	0.2	1.1	3.0	0.7
Pb	0.1	4.0	15.5	1.1
Se	< 0.001	4.912	1.965	1.965
V	0	0	0	0
Zn	0.25	9.60	42.1	3.55
Chlorodane ug/L	-	0	-	-
Dieldrin ug/L	-	0	-	-
PCB "	-	0	-	-
TSS	40	641	3162	170
pH	3.15	2.84	2.94	2.80
TC	13	7	9	10
TOC	7	6	6	7

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TABLE A-7 (Cont'd.)

LABORATORY ANALYSES
SCRUBBER EFFLUENT (SAMPLES NO.7) AND TAP WATER (SAMPLE NO.8)
(CONCENTRATIONS IN mg/l - Except Where Noted)

SAMPLE #	7 - 5	7 - 6	7 - 7	7 - 8	8 - 1
DATE	8/29	8/30	8/30	8/29	
TIME					
Ag	0.02	0.01	0.01	0.04	0
As	94	117	97	85.5	0
Be	0	0	0	0	0
Cd	0.25	0.32	0.28	0.051	0
Cr^{+3}	0.84	2.70	2.55	1.80	0
Cr^{+6}	----------less than 0.01 ppm----------				
Total Cr	0.84	2.70	2.55	1.80	0
Cu	0.84	0.89	0.58	3.70	0.04
Fe	94	117	97	85.5	0.04
Hg	0.0402	0.0529	0.0506	0.0437	0.0007
Mn	0.25	0.32	0.28	0.51	0
Ni	0.8	1.1	0.9	0.9	0
Pb	1.0	5.5	3.6	7.6	0.05
Se	< 0.001	1.965	1.965	0.98	< 0.001
V	0	0	0	0	0
Zn	0.02	0.01	0.01	0.04	0.03
Chlorodane ug/L	-	-	-	-	-
Dieldrin ug/L	-	-	-	-	-
PCB "	-	-	-	-	-
TSS	218	237	162	1358	1
pH	2.80	2.50	2.82	2.64	-
TC	10	9	8	8	33
TOC	6	7	5	6	7

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APPENDIX C

ADDITIONAL ANALYSES OF MRC SAMPLES

In the following tables are metal concentrations determined in ISC labs by AA analysis of HF-digested samples. These samples were the HNO_3-insoluble residues remaining from MRC's digestion procedure.

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TABLE C-1
ANALYSIS OF NITRIC ACID-INSOLUBLE RESIDUE BY ISC LABS

(VALUES IN MICROGRAMS)

SASS RUN 1

ELEMENT	-------PARTICULATE SIZE FRACTION (MICRONS)------			
	>10	3-10	1-3	0.1-1
AG	1.50	0.0	0.0	0.0
BE	0.0	0.0	0.0	0.0
CD	0.99	0.0	0.0	0.0
CR	37.50	0.0	0.0	0.0
CU	5.01	0.0	0.0	0.0
FE	549.99	0.0	0.0	0.0
MN	7.00	0.0	0.0	0.0
NI	30.05	0.0	0.0	0.0
PB	15.01	0.0	0.0	0.0
V	0.0	0.0	0.0	0.0
ZN	59.99	0.0	0.0	0.0
HG	0.03	0.0	0.0	0.0

TABLE C-2
ANALYSIS OF NITRIC ACID-INSOLUBLE RESIDUE BY ISC LABS

(VALUES IN MICROGRAMS)

SASS RUN 2

ELEMENT	-------PARTICULATE SIZE FRACTION (MICRONS)------			
	>10	3-10	1-3	0.1-1
AG	14.03	202.03	38.20	0.0
BE	0.0	0.0	0.0	0.0
CD	14.35	53.77	3.99	0.0
CR	351.61	418.73	88.36	0.0
CU	287.83	566.99	44.79	0.0
FE	9132.27	107990.00	17147.05	0.0
MN	91.69	202.03	14.57	0.0
NI	70.16	135.23	13.20	0.0
PB	1264.52	22542.99	4115.26	0.0
V	0.0	0.0	0.0	0.0
ZN	1264.52	4454.51	514.35	0.0
HG	3.37	1.89	0.21	0.0

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TABLE C-3
ANALYSIS OF NITRIC ACID-INSOLUBLE RESIDUE BY ISC LABS

(VALUES IN MICROGRAMS)

SASS RUN 3

ELEMENT	>10	3-10	1-3	0.1-1
	-------PARTICULATE SIZE FRACTION (MICRONS)------			
AG	10.73	250.71	46.48	0.0
BE	0.0	0.0	0.0	0.0
CD	10.73	34.12	1.81	0.0
CR	101.31	433.18	69.72	0.0
CU	229.45	605.27	43.80	0.0
FE	5866.35	77598.94	5539.62	0.0
MN	79.84	170.60	8.89	0.0
NI	53.67	114.22	8.89	0.0
PB	906.39	6276.69	1179.36	0.0
V	0.0	0.0	0.0	0.0
ZN	853.38	3765.12	384.22	0.0
HG	0.85	3.19	0.36	0.0

TABLE C-4
ANALYSIS OF NITRIC ACID-INSOLUBLE RESIDUE BY ISC LABS

(VALUES IN MICROGRAMS)

SASS RUN 4

ELEMENT	>10	3-10	1-3	0.1-1
	-------PARTICULATE SIZE FRACTION (MICRONS)------			
AG	37.14	31.74	2.95	0.0
BE	0.0	0.0	0.0	0.0
CD	37.14	12.53	1.47	0.0
CR	720.49	253.10	41.61	0.0
CU	814.57	284.84	20.42	0.0
FE	83351.19	35410.04	2189.63	0.0
MN	302.06	95.22	7.32	0.0
NI	190.64	63.48	7.32	0.0
PB	3599.96	1770.84	80.26	0.0
V	0.0	0.0	0.0	0.0
ZN	1705.90	1517.74	240.84	0.0
HG	2.28	0.76	0.09	0.0

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TABLE C-5
ANALYSIS OF NITRIC ACID-INSOLUBLE RESIDUE BY ISC LABS

(VALUES IN MICROGRAMS)

SASS RUN 5

ELEMENT	>10	3-10	1-3	0.1-1
	-------PARTICULATE SIZE FRACTION (MICRONS)------			
AG	46.45	70.86	7.41	0.0
BE	0.0	0.0	0.0	0.0
CD	45.38	10.12	2.17	0.0
CR	451.15	210.34	46.74	0.0
CU	1098.51	383.56	52.10	0.0
FE	94113.56	47498.05	3402.90	0.0
MN	396.66	131.60	13.79	0.0
NI	224.64	101.23	10.60	0.0
PB	2629.04	707.50	106.36	0.0
V	0.0	0.0	0.0	0.0
ZN	3548.48	1111.30	319.09	0.0
HG	1.77	0.40	0.11	0.0

TABLE C-6
ANALYSIS OF NITRIC ACID-INSOLUBLE RESIDUE BY ISC LABS

(VALUES IN MICROGRAMS)

SASS RUN 6

ELEMENT	>10	3-10	1-3	0.1-1
	-------PARTICULATE SIZE FRACTION (MICRONS)------			
AG	12.52	34.17	1.00	0.0
BE	0.0	0.0	0.0	0.0
CD	18.01	34.17	0.50	0.0
CR	236.13	553.56	1.30	0.0
CU	361.53	578.95	8.00	0.0
FE	7667.61	21618.21	185.00	0.0
MN	89.86	112.27	1.00	0.0
NI	58.24	86.89	0.0	0.0
PB	1598.97	4237.14	35.00	0.0
V	0.0	0.0	0.0	0.0
ZN	1886.36	5947.75	120.00	0.0
HG	1.08	0.69	0.03	0.0

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TABLE C-7
ANALYSIS OF NITRIC ACID-INSOLUBLE RESIDUE BY ISC LABS

(VALUES IN MICROGRAMS)

SASS RUN 7

ELEMENT	-------PARTICULATE SIZE FRACTION (MICRONS)------			
	>10	3-10	1-3	0.1-1
AG	13.27	94.97	3.93	0.0
BE	0.0	0.0	0.0	0.0
CD	15.90	44.21	1.32	0.0
CR	194.14	955.20	19.65	0.0
CU	359.00	549.35	20.97	0.0
FE	14279.14	13897.93	642.15	0.0
MN	69.89	94.97	2.61	0.0
NI	61.99	63.04	0.0	0.0
PB	3229.98	4421.80	131.05	0.0
V	0.0	0.0	0.0	0.0
ZN	1999.06	6254.05	314.54	0.0
HG	0.45	0.88	0.08	0.0

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